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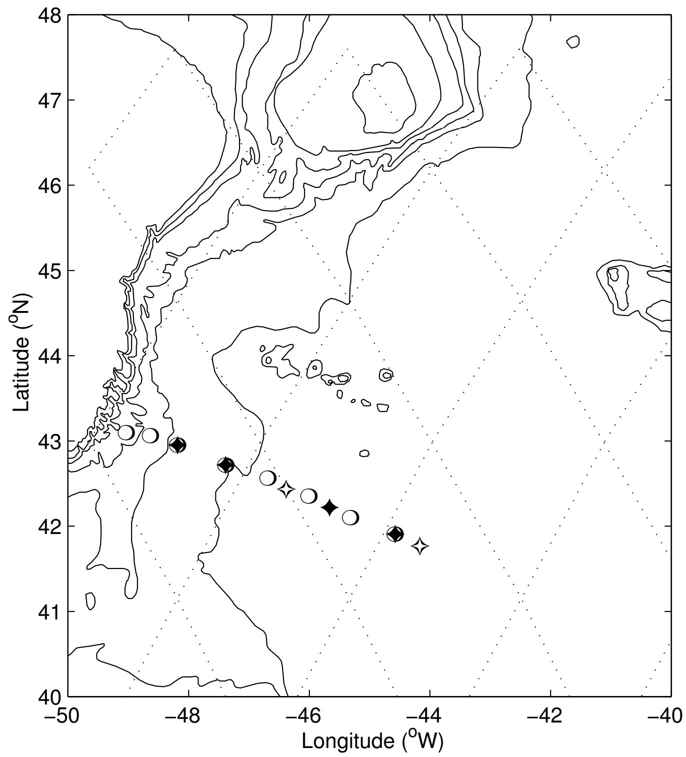
North Atlantic Current Inverted Echo Sounder Data Report for August 1993 – July 1995



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1 Introduction

This report focuses on data from inverted echo sounders with pressure gauges (PIES) spanning the North Atlantic Current (NAC) east of the Grand Banks collected during August 1993 to July 1995. In this report the collection, processing and calibration of the PIES data are described and plotted. The measurements were made under the support of the Office of Naval Research and the National Oceanographic and Atmospheric Administration. Other data collected as part of the experiment included conductivity-temperature-depth (CTD) hydrographic surveys and velocity measurements obtained with moored current meters, shipboard acoustic Doppler current profilers, and POGO floats. These data were collected jointly by the Bedford Institute of Oceanography and the University of Rhode Island.

The sites of all the moored instruments are shown in Figure 1. The single line of instrumentation consisted of 8 tall current meter moorings, with six PIESs interspersed. Each tall mooring consisted of 5–7 current meters at selected nominal depths of 400, 800, 1500, 2500, 3500, 4000 m, and 100 m off the bottom. The current meter records are not documented in this report.

Table 1 and Figure 2 summarize the deployment location and data returns of each of the PIESs. The instruments were deployed on a cruise aboard the R/V Oceanus (OC259–Leg II), during July 30–August 10, 1993. The PIES instruments were recovered during June 7–July 5, 1995 aboard the CSS Hudson (HU95011). Of the six PIES deployed, two of the instruments were not recovered. The losses occurred at PIES95NAC55, located near the middle of the array line, and PIES95NAC85, the site farthest offshore. Neither of these instruments responded to release signals and neither was heard sampling when its site was visited during the recovery cruise. Since seawater was found in two of the recovered PIESs (one of which had a puzzling crack in the glass sphere), it is postulated that water leaked into the unrecovered instruments as well, destroying their electronics. The most probable reason for the leaks was the use of an electric hand drill to tighten the external steel bands around the glass

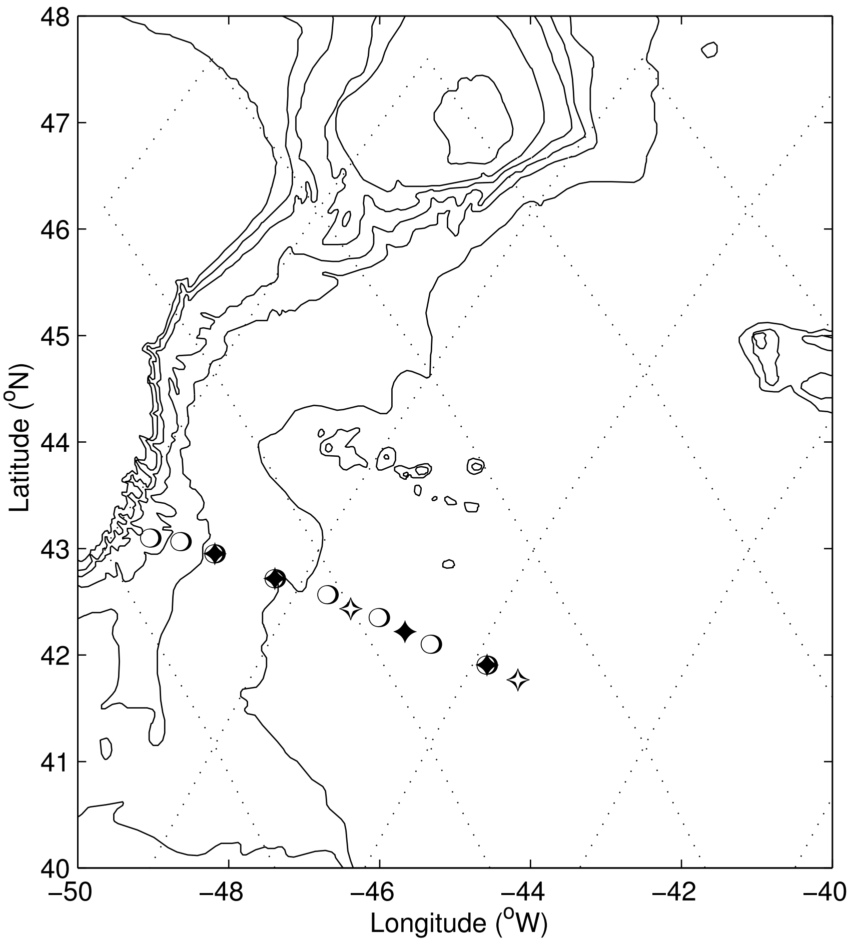

Figure 1: Locations of 8 current meter moorings (circles) and 6 PIESs (diamonds; solid and open symbols respectively denote recovered and lost instruments) deployed across the North Atlantic Current. The dotted lines crossing diagonally represent the ground tracks of the TOPEX/POSEIDON satellite. Bottom depths of 200 m, 500 m, 1000 m, 2000 m, 3000 m, and 4000 m are shown.

housing prior to launch; excessive tightening of the bands appeared to have caused the sealant in the joint between the two glass hemispheres to be extruded allowing slow leaks to occur.

Complete travel time, pressure and temperature records were obtained for 3 of the 4 recovered instruments. For the remaining instrument, PIES95NAC65, several problems were encountered which may have been caused by the seawater that leaked inside the glass sphere. Travel time data were obtained for 20 months of the 23-month deployment period. During the final 3 months of the record, null values were recorded for all 24 pings of each travel time burst sample. Although the data were calibrated and documented in this report, upon further examination it was determined that they are unreliable and should not been used in any subsequent analyses. In addition, only a partial temperature record was obtained for this instrument. Nonetheless the record was of sufficient quality to be used to calibrate the pressure measurements. Fortunately no problems were encountered with the pressures measured by this instrument and a complete, high quality record was obtained.

2 Inverted Echo Sounder Description

The inverted echo sounders used in the NAC experiment were built at URI using the instrument design (Model 1665) of Sea Data Corp. In addition to the travel time

Table 1: **North Atlantic Current PIES Location and Record Information**

Site	Lat(N)	Lon(W)	1st Point	Last Point	Comments
PIES95NAC30	42°57.04′	48°10.96′	01-Aug-93	01-Jul-95	OK
PIES95NAC40	42°43.04′	47°23.21′	02-Aug-93	30-Jun-95	Small amount of water inside
PIES95NAC55	42°26.06′	46°22.97′	**lost**		No response
PIES95NAC65	42°13.18′	45°39.84′	04-Aug-93	29-Jun-95	Approximately 8 oz of water inside; Last 2/3 of temperature record is bad; Travel times quit during final 3 months of record and the values are questionable
PIES95NAC80	41°54.36′	44°34.46′	05-Aug-93	29-Jun-95	OK
PIES95NAC85	41°46.02′	44°09.96′	**lost**		No response

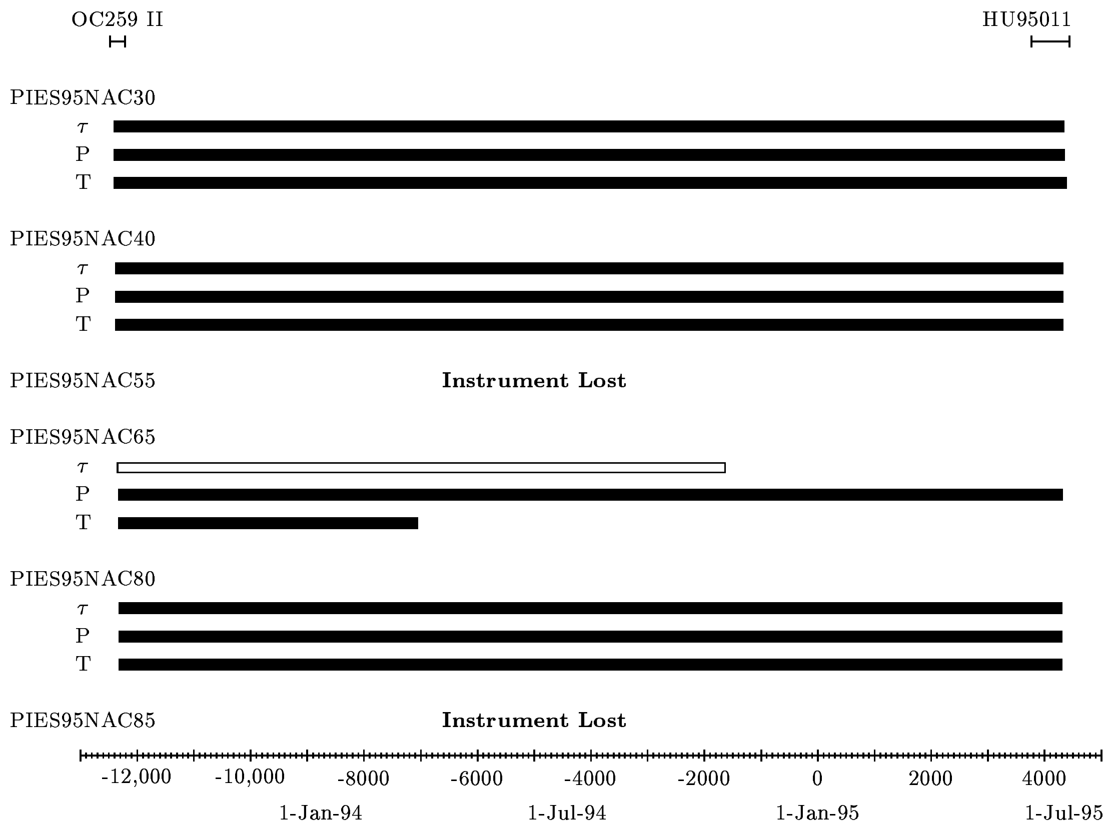

Figure 2: Solid boxes inidcate the timelines of good data for the PIESs deployed in the North Atlantic Current. The hourly travel time (τ), pressure (P), and temperature (T) records are shown. The open box used for the τ measurements at site PIES95NAC65 indicates that the values are unreliable. The durations of the launch and recovery cruises are also indicated. The time axis at the bottom indicates yearhours relative to January 1, 1995; large and small ticks denote increments of 1000 hr and 100 hr respectively.

detector, these instruments were also equipped to measure pressure and temperature. Chaplin and Watts [1984] provide a description of the IES circuitry and mooring configuration and Watts and Kontoyiannis [1986] describe instruments with pressure and temperature sensors included.

The instruments were moored one meter above the ocean floor and sampled at hourly intervals throughout the deployment period. At the designated sampling time, a burst of 24 acoustic pulses (10 KHz) were transmitted at 10 second intervals, and the time each ping took to travel the round trip distance to the sea surface was measured.

For typical deployment depths of 3000–5000 m, the full travel times (τ) range between 4–7 s; thus with a resolution of 0.05 ms, each measurement would require a storage space of 18 bits on the internal cassette tape. However since the variability of the travel time signal in major current regions such as the North Atlantic Current is only 0.03–0.06 s, it is not necessary to record the full τ measurement. By recording just the 13 least significant bits, variability of up to 0.4 s can be resolved, with only a constant integer multiple of 0.4 s excluded. The constant can be determined a priori by knowing the bottom depth at the instrument site to within 300 m; it may be added back into the recorded travel times after the instrument is recovered. The advantage of recording only the variable part of the τ measurements is that space is conserved on the cassette tape, allowing the length of deployment to be extended.

Digiquartz pressure sensors (models 46K-017 and 46KT-074) manufactured by Paroscientific Inc. were used to measure bottom pressure. Unlike τ which is burst sampled, the pressure measurement was an average over the full sampling period (one hour). All pressure measurements were corrected for the temperature sensitivity of the transducer. The pressures were resolved to 0.001 dbar and have an accuracy of 0.01% of full scale, or 0.5 dbar for water depths up to 6000 m (R. Wearn, personal communication).

Temperatures were measured using thermistors (Yellow Springs International Corp.,

model 44032) controlled by Sea Data Corp. (model DC-37B) electronics cards installed in the PIESs. Their main purpose was to correct the pressure measurements. The thermistor was located inside the instrument on the pressure transducer rather than being directly in the water. Thus it takes approximately 12 hours after launch for the temperature probe to reach equilibrium with the surrounding waters to within 0.001°C. However, once equilibrium has been reached, the thermistor also provides measurements of the bottom temperature fluctuations, which are effectively low-pass filtered with a 2 hour e-folding equilibration time. Temperature measurement was an average over slightly less than a minute, taken at the very end of each hourly sampling period. The absolute accuracy of the temperature measurement is 0.15°C and the resolution is 0.0007°C.

The sampling strategies of travel time, pressure and temperature must be taken into account when determining the time associated with each variable. Since the duration and temporal positioning of the variables differ within the sampling period, the centers of their measuring intervals do not coincide, as illustrated in Figure 3. All timing is referenced to the transmission time of the first travel time ping in a sample burst as it is easily observed. The midpoint of the burst of 24 τ measurements is located at 115 s, since the pings were sent at 10 s intervals. The hour-long pressure measurement actually begins 11.25 s prior to the first τ ping at a time when the PIES does its internal bookkeeping and storage to tape. Thus the midpoint of pressure is assigned a time of 1788.75 s ($1800 - 11.25$ s) after the first τ. The temperature is measured only for a 56.25 s (a sixty-forth of an hour) interval at the end of the sampling period, just prior to the internal bookkeeping. Thus the midpoint of temperature is assigned the time of 3560.625 s ($3600 - 56.25/2 - 11.25$ s) after the first τ ping. Since the τ, pressure and temperature records are low-pass filtered prior to use in subsequent analyses, these timing differences are not crucial. However accurate timing is important to determine the exact phase of the tidal constituents from the pressure records.

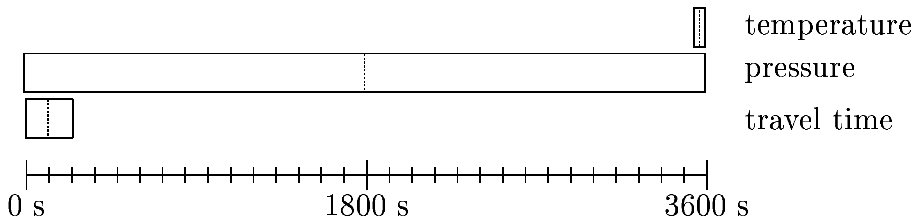

Figure 3: Sampling Sequence of Sea Data Model PIESs. The horizontal length and position of the boxes represent the duration and relative timing of the measurements of travel time, pressure, and temperature during each sampling period. The midtime of each variable is indicated by a dotted line. Tick marks represent 2 minute intervals.

3 Data Processing and Calibration

The basic steps in the PIES data processing included transcription from the cassette tape, editing to remove data spikes, and conversion of the recorded counts into scientific units. The data processing was accomplished by a series of FORTRAN routines specifically developed for the PIES [Fields *et al.,* 1991]. The final low-pass filtering step was performed using MATLAB [The MathWorks, Inc., 1992].

3.1 Travel Time Calibration

From the 24 travel times taken each sampling period, a single representative τ was chosen by using the modal value of a windowed Rayleigh distribution [Watts and Rossby, 1977; Fields *et al.,* 1991]. Prior to low-pass filtering, travel times were adjusted by removing the variability associated with the development of the seasonal thermocline. The final calibration step was to project the measured travel times on to a common pressure level.

3.1.1 Seasonal Correction

Warming and cooling of the surface layer produces seasonal variations in the speed of sound traveling through the layer. This, in turn, gives rise to seasonal

variations in the PIES τ measurements.

To resolve the seasonal τ cycle in the NAC region, the maximum depth of the seasonal thermocline was determined using historical hydrographic data obtained from the HydroBase database [Lozier, Owens, and Curry, 1995] for the region described by the Marsden Square 40–50°N, 40–50°W. The hydrocasts were restricted to be located in the NAC and the offshore regions by selecting only the stations where the depth of the 10°C isotherm exceeded 300 dbars. In all, 2859 hydrocasts were selected for use. From each cast, temperatures at the 50, 100, 200, 300, 400, 500, and 600 dbar levels were determined. These data were sorted by yearday, grouped into 14-day bins, and averaged. Figure 4 shows the 14-day-average temperatures as functions of time for all but the two deepest levels. Third order polynomials were fitted to the temperatures at each level using the "polyfit" function of MATLAB and the resulting curves are also shown in Figure 4. These curves were simply a visual convenience and were not used further. Seasonal warming and cooling is clearly evident in the temperatures at 50–200 dbars and the temperatures at and below 300 dbars are relatively uniform. Based on this figure, it was determined that seasonal warming was confined to the upper 300 dbar in this oceanic region and that the seasonal fluctuations in τ would be determined only for this layer.

Using all the HydroBase CTDs in the selected Marsden Square, sound speed profiles were determined between the sea surface and 300 dbar and integrated to obtain acoustic travel time (τ_{300}). A plot of τ_{300} versus yearday exhibited two major clusters, one centered near $\tau_{300} = 0.405$ s and the other near $\tau_{300} = 0.395$ s. Most of longer τ_{300} were associated with hydrocasts located on the shoreward side of the NAC, whereas the shorter τ_{300} were associated with casts in the NAC and farther offshore. To minimize the scatter due to the change in water masses across the front, we initially selected only the hydrocasts with $\tau_{300} < 0.397$ s to determine the seasonal curve. Furthermore, all hydrocasts located south of 41°N were eliminated to ensure that any measurements in the Gulf Stream or Azores Current were excluded.

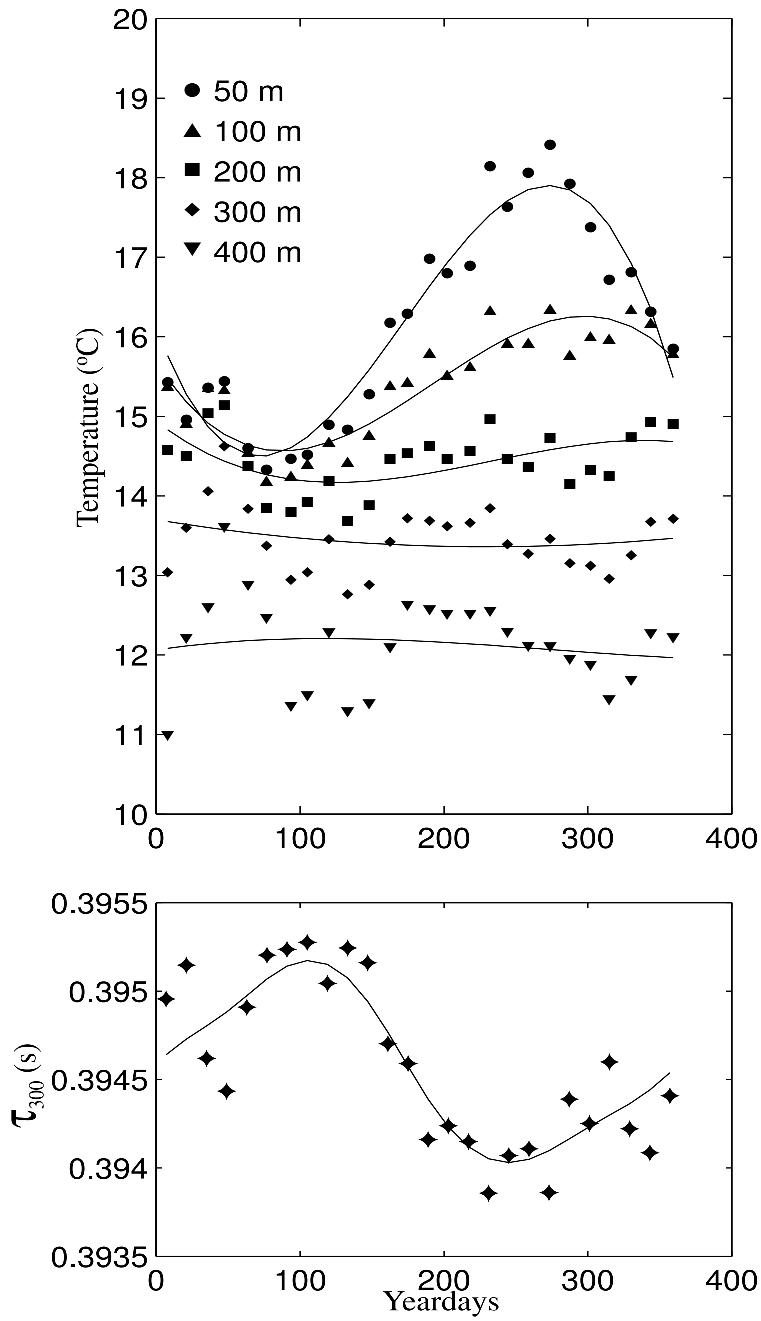

Figure 4: (Top) Plot of temperatures versus yearday for several pressure levels in the upper 400 dbar. (Bottom) The corresponding τ_{300} integrated for the upper 300 dbar plotted versus yearday. The solid curve was obtained by low-pass filtering the τ_{300} values as described in the text.

As was done previously for temperature, the τ_{300} were sorted into 14-day bins and averaged (Figure 4). To obtain a smoothed representation of the seasonal cycle, we first created a three-year-long time series by replicating the 14-day-averaged τ_{300}. Subsequently the 3-year-long record was smoothed with a 156-day low-pass filter, but only the central one-year portion was retained. The smoothed τ_{300} curve is superimposed in Figure 4. τ_{300} was found to vary by as much as 1.1 ms with the maximum occurring in April and the minimum in September.

Since the IES at site 3.0 was on the shoreward side of the NAC, we also examined the seasonal curve for the region inshore of the NAC (hydrocasts for which $\tau >$ 0.397 s). The data from this region exhibited more scatter and were sparser between mid-September and early April, thus the seasonal cycle was not as well resolved. Nevertheless, the seasonal cycle had essentially the same shape as that obtained for the offshore region but with a slightly smaller peak-to-peak amplitude. Because of the similarity between the two seasonal curves, we felt justified in applying only the better resolved curve shown in Figure 4 to all four PIES measurements.

The relative differences between the smoothed τ_{300} values for the first day of each month and the April (yearday = 91) value were determined. These differences were subsequently linearly interpolated to the time of each sample and added to the measured travel times, thereby removing the average seasonal variability. Because the actual seasonal variations may differ from this average cycle, we estimated the residual error in τ by examining the standard error of the smoothed τ_{300} curve. First, the appropriate seasonal value was removed from the τ_{300} obtained for each hydrocast. Subsequently the residuals were grouped into the same 14-day bins and the standard error of the mean was determined for each bin. Because the errors ranged between 0.06 and 0.16 ms, it was concluded that a reasonable estimate for the residual error in τ would be 0.2 ms. The seasonally-corrected τ records for the four NAC PIESs are shown in Figures 8–11.

3.1.2 Calibration to τ_{2000}

It has been our practice [e.g., Watts and Johns, 1982; Tracey and Watts, 1986; Watts et al., 1995] to calibrate the seasonally-corrected τ measurements into main thermocline depths (Z_T) using temperature profiles obtained from XBTs. Subsequently these Z_T values were converted into other quantities, such as dynamic height ΔD [Kim and Watts, 1994; He, 1993], for additional analyses. Figure 5 illustrates the relationships between several quantities and travel times calculated from hydrography where the seafloor pressure was simulated to be 3500 dbar. Because scatter occurs in the relationships between τ and Z_T (lower right panel in the figure), the two-step calibration process $\tau \rightarrow Z_T \rightarrow \Delta D$ introduces more noise in the final quantities than would be obtained if the measured τs were calibrated directly into ΔD (upper left panel in Figure 5).

Relationships such as those shown in Figure 5 are specific to travel time measurements obtained with an instrument deployed at 3500 dbars. However in practice, bottom depths at the PIES sites vary from site to site and never exactly coincide with the 3500 dbar level. Therefore either a suite of relationships like those in Figure 5 must be created for each PIES specific to the deployment depth, or the measured τs must be projected onto a common pressure level. The latter of these two options was considered to be the most practical and the 2000 dbar level was chosen as the common level, since a large fraction of the available hydrographic data extended to that level.

To determine the projections, we used hydrographic data collected in the Newfoundland Basin during July 1993 (OC259 leg I), August 1993 (OC259 leg II) November–December 1993 (HU93039), October–November 1994 (HU94030), April–May 1995 (HU95003), and June–July 1995 (HU95011) by scientists from the Bedford Institute of Oceanography and the University of Rhode Island. Additionally hydrographic data collected in the Newfoundland Basin by Peter Koltermann during July 1993 and November 1994 were also used for these determinations. Each hydrocast was

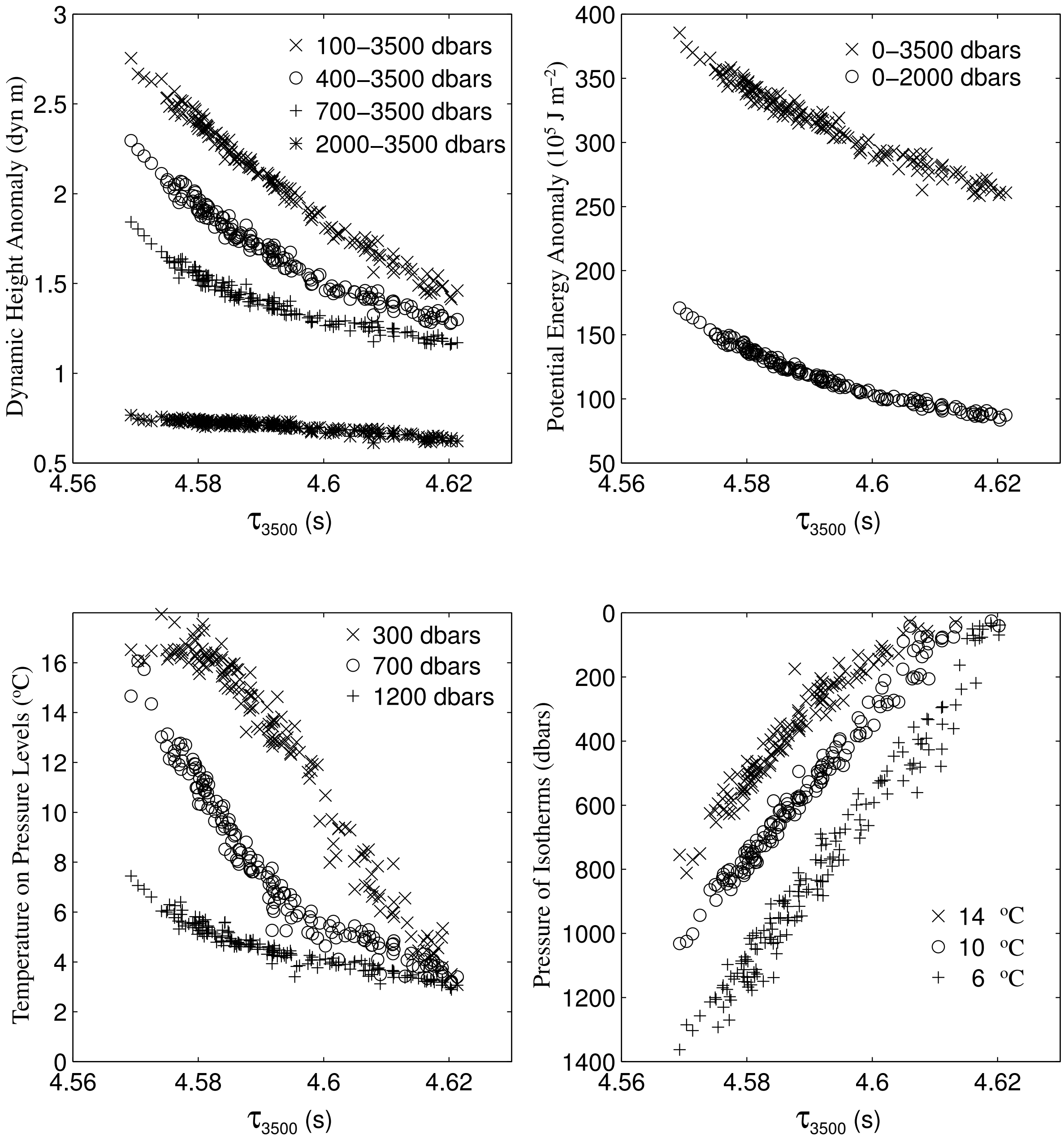

Figure 5: Examples of oceanographic quantities that are related to round trip travel time. All quantities are simulated from CTD data taken in the Newfoundland Basin during 1993–1995. The travel times (τ_{3500}) simulate measurements that would be obtained by an instrument moored at a bottom pressure of exactly 3500 dbars. Dynamic height anomaly and potential energy anomaly were integrated over the suite of pressure ranges indicated in the respective panels.

integrated from a suite of pressures (p) to simulate the round trip travel times (τ_p) to the surface that would be obtained from instruments deployed at those depths. For this study, τ_p was simulated for bottom pressures between 2000–5000 dbar at 250 dbar intervals. Plotting τ_p for one pressure versus those of another level revealed that they are linearly related as long as both levels are significantly below the main thermocline. Figure 6 shows examples of the relationships for travel times at 2000 dbar (τ_{2000}) versus τ_p obtained for pressure levels 2500, 3250, and 4750 dbar.

The slopes **A** and intercepts **B** of these relationships can be determined. However because the variations in τ_p are on the order of tens of milliseconds while the magnitudes are on the order of several seconds, large errors can arise when determining these parameters. To minimize the errors, **A** and **B** were obtained using only the τ_p variability, determined by removing a large constant from the travel times. This constant, τ_{ms}(p), was defined as the round trip travel time that would be measured if the sound speed in the ocean was fixed at 1500 m s^{-1}. Thus

$$\tau_{ms}(p) = \frac{2\left(\frac{p}{1.017}\right)}{1500}$$

where the factor 1.017 dbar m^{-1} is used to convert the bottom pressure in decibars to depth in meters, with adequate accuracy for the purpose of removing a constant.

Slightly different slopes and intercepts were obtained for the relationships between τ_{2000} and τ_p for $2000 \leq p \leq 5000$ dbar. Figure 7 shows that the values obtained for **A** and **B** were related to the bottom pressure. No dynamical justification could be determined for the observed structure in **A** for $p \geq 4000$ dbar; instead the structure was attributed to the limited number of hydrocasts extending to the deeper levels. Superimposed in the figure are the best-fit curves, which were defined as

$$\mathbf{A}(p) = \begin{cases} a_1 p^3 + a_2 p^2 + a_3 p + a_4 & \text{for } p \leq 3750 \\ 9.4833 \times 10^{-01} & \text{for } p > 3750 \end{cases}$$
$$\mathbf{B}(p) = b_1 p^3 + b_2 p^2 + b_3 p + b_4$$

where $a_1 = 8.5174 \times 10^{-12}$, $a_2 = -7.1524 \times 10^{-08}$, $a_3 = 1.6291 \times 10^{-04}$, $a_4 = 8.9151 \times 10^{-01}$, $b_1 = -5.8012 \times 10^{-13}$, $b_2 = 1.4222 \times 10^{-08}$, $b_3 = -5.2794 \times 10^{-05}$, and $b_4 =$

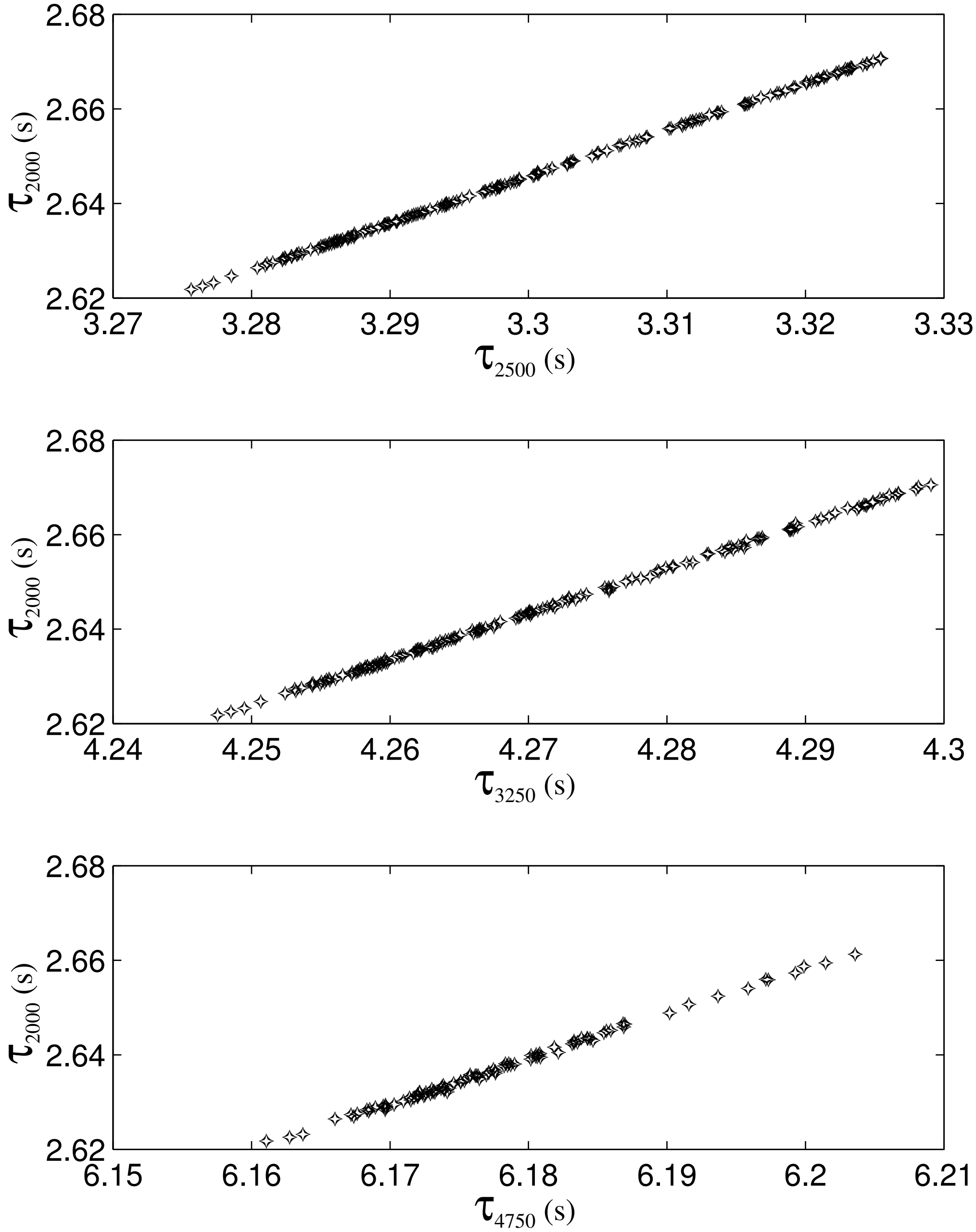

Figure 6: Comparison of the round trip travel time for a bottom pressure of 2000 dbars with the travel times for bottom pressures of 2500 dbars (top), 3250 dbars (middle), 4750 dbars (bottom).

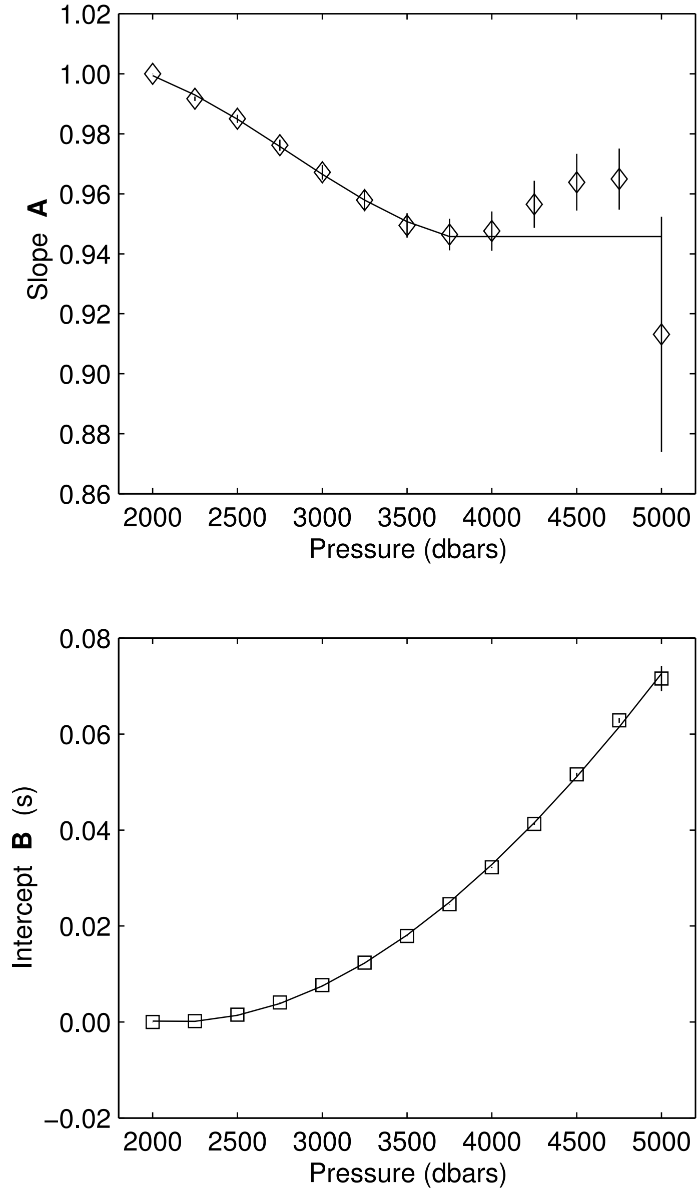

Figure 7: Slope **A** (top) and intercept **B** (bottom) plotted as functions of bottom pressure. Error bars indicate the 95% confidence limits.

5.3547×10^{-02}. The slopes for the deeper levels are forced to equal that obtained for $p = 3750$ dbar to avoid introducing any non-dynamical variability.

Since the four PIESs deployed in the NAC were equipped with pressure sensors, the bottom pressure at each site was determined by averaging the deployment-long measurements. However, two adjustments to these values were required before applying them to the above formulas. First, the mean regional atmospheric pressure of 10.2 dbar was removed, since the pressure sensors measured absolute, not gauge, pressure. Second, 0.6 dbar was subtracted to account for the physical separation between the locations of the pressure sensor and the transducer on the PIES. After incorporating these adjustments, the mean pressures were used in the above equations to determine the appropriate **A** and **B** for each instrument. Finally, the travel times measured by each of the instruments were projected onto τ_{2000} using

$$\tau_{2000} = \mathbf{A}(p) * \{\tau_P - \tau_{ms}(p)\} + \mathbf{B}(p) + \tau_{ms}(2000)$$

Contributing to the uncertainty in τ_{2000} are the accuracy of the travel time measurements, $\epsilon_\tau = 1.0$ ms [Chaplin and Watts, 1984], and the accuracy of the pressure measurements, about 0.5 dbar which is equivalent to a $\epsilon_p = 0.7$ ms error in travel time. Additional error in τ_{2000} arises from the projection to 2000 dbar from the actual bottom pressure. These errors are due to the scatter about the **A** and **B** versus pressure curves. The maximum scatter in the **A** versus pressure curve (Figure 7) was obtained for pressures of 5000 dbar and corresponds a maximum error of 1 ms in τ. Similarly, the greatest scatter in the B versus pressure curve also occurred at 5000 dbar, contributing a 1 ms error in τ_{2000}. However, **A** and **B** have opposing effects on τ_{2000} and so their errors should primarily cancel. The combined error $\epsilon_{\mathbf{AB}}$ was determined by quantifying the scatter of the τ_{2000} versus τ_p relationships shown in Figure 6. The scatter ranged from 0.1 ms to 0.7 ms for all levels, except for $\tau_p = 5000$ dbar where the scatter was 1.2 ms. Specifying $\epsilon_{\mathbf{AB}} = 1.0$ ms, the total error in τ_{2000} is estimated to be $(\epsilon_\tau^2 + \epsilon_p^2 + \epsilon_{\mathbf{AB}}^2)^{\frac{1}{2}} = 1.6$ ms.

The τ_{2000} records were subsequently low-pass filtered using a second-order But-

terworth filter with a cutoff period of 40 hours. The filter was passed forward and backward in time to avoid introducing phase shifts. Twenty hours of data at each end of the filtered series were discarded to avoid startup transients. After filtering, the timeseries were subsampled at 6-hour intervals centered at 0000, 0600, 1200, 1800 UT. The low-pass filtered τ_{2000} records are shown in Figure 24.

3.2 Temperature

The hourly temperature records are shown in Figures 20–23. The temperature record for site PIES95NAC65 drifted to lower values and an exhibited excessive number of large data spikes after approximately 7 months. These data were considered bad and therefore were discarded. The temperature records of the remaining three PIESs did not drift.

Since the temperature probes are mounted inside the pressure housing, they required nearly 12 hours to reach equilibrium with the surrounding seawater to within 0.001°C. Therefore, the first 12 points of each temperature record were dropped prior to low-pass filtering. The temperature records were low-pass filtered in the same manner as the τ_{2000} records and are shown in Figure 26.

3.3 Bottom Pressure

All pressure measurements were corrected for the temperature sensitivity of the transducer, using calibration coefficients supplied by the manufacturer. Since the temperature record at site PIES95NAC65 failed part way through the deployment period, the pressures in the final portion of the record were corrected using a fixed temperature of 2.44°C, the mean of the initial 7 months of good temperature measurements. Testing on the initial portion of the record showed that pressures determined using the fixed temperature typically differed from those obtained with the measured temperatures by 0.01 dbar or less and that the maximum differences were only 0.02 dbar.

The hourly measured bottom pressures (Figures 12–15) are dominated by tides. Tidal response analysis [Munk and Cartwright, 1977] was used to determine the tidal constituents for each instrument. The calculated tides were then removed from the pressure records. The amplitudes, H (dbar), and phases, $G°$ (Greenwich epoch), of the constituents are given in the tables in Section 4. The residual pressure records are shown in Figures 16–19 with the initial 12 hours of data removed since the temperature of the crystals had not reached equilibrium.

The residual pressure records were examined for long term drifts. Drift rates of 1.43×10^{-4} dbar d^{-1}, -9.86×10^{-5} dbar d^{-1}, 6.42×10^{-5} dbar d^{-1}, 1.82×10^{-6} dbar d^{-1} were obtained for sites PIES95NAC30, PIES95NAC40, PIES95NAC65, and PIES95NAC80, respectively. Except for site PIES95NAC30, these drift rates were nearly an order of magnitude smaller than those obtained during previous deployments. Therefore, it was decided not to remove them from the pressure records in case they represent true oceanographic signals.

The residual pressure records were low-pass filtered (Figure 25) as described above for τ_{2000}.

3.4 Time Base

The date and time were assigned to each sampling period and these are listed in Tables 2– 5 in Section 4. Times are given as Universal Time (UT). For processing convenience, the times were converted into yearhours; there are 8760 hours in a standard year. The yearhours given in this report are referenced to January 1, 1995 at 0000 UT, with measurements occurring between January and July 1995 assigned positive yearhours and those between August 1993 and December 1994 assigned negative values.

4 Individual Site and Record Information Tables

The tables that follow provide information about the location, data, and basic statistics of the data records. Each table documents a single instrument. General information such as position, bottom depth, and launch and recovery times is given first. Details about the travel time, pressure, and temperature records that are plotted in Sections 5–6 are tabulated. Tables supply the times associated with the first and last point in each plot. All yearhours are referenced to January 1, 1995 at 0000 UT.

First order statistics are tabulated for both hourly and six-hourly low-pass filter records (40HRLP) of each variable.

The constant (integer multiple of 0.4 s) needed to convert the recorded travel time measurements to absolute travel times is also listed for each instrument.

Table 2: **Site and Record Information for PIES95NAC30**

Serial Number: 69
Type of Travel Time Detector: TTC
Number of Pings per Sampling: 024
Additional Sensors: Pressure and Temperature
Pressure Sensor Serial Number: 33816

POSITION: 42°57.04N 48°10.96W   DEPTH: 3275 m

	DATE	GMT	CRUISE
LAUNCH:	Aug 1, 1993	1709	OC259
RECOVERY:	Jul 1, 1995	0615	HU95011

TRAVEL TIME RECORDS

Figure 8

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 1, 1993	180228	–12413.96
LAST DATA POINT:	Jul 1, 1995	050228	4349.041

Number of Points: 16764
Sampling Interval: 1.0 hr

Minimum = 0.36548 s   Mean = 0.38010 s
Maximum = 0.39041 s   Standard Deviation = 0.00484 s
Unrecorded Constant = 4.0 s

40HRLP τ_{2000} RECORDS

Figure 24

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 2, 1993	1800	–12390
LAST DATA POINT:	Jun 30, 1995	0600	4326

Number of Points: 2787
Sampling Interval: 6.0 hrs

Minimum = 2.6546 s   Mean = 2.6675 s
Maximum = 2.6764 s   Standard Deviation = 0.0046 s

MEASURED PRESSURE RECORDS

Figure 12

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 1, 1993	193000	–12412.5
LAST DATA POINT:	Jul 1, 1995	043000	4348.5

Number of Points: 16762
Sampling Interval: 1.0 hrs

Minimum = 3313.62 dbar   Mean = 3324.10 dbar
Maximum = 3324.60 dbar   Standard Deviation = 0.18 dbar

RESIDUAL PRESSURE RECORDS

Figure 16

$$P_{residual} = P_{measured} - MEAN - TIDE$$

TIDE calculated from the following constituents:

	M2	N2	S2	K2	K1	O1	P1	Q1
H (dbar):	0.21370	0.04631	0.07911	0.02121	0.05465	0.03788	0.01820	0.00657
G°:	346.645	330.860	24.224	27.283	155.277	155.360	155.538	152.450

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 2, 1993	063000	–12401.5
LAST DATA POINT:	Jul 1, 1995	043000	4348.5

Number of Points: 16751
Sampling Interval: 1.0 hrs

Minimum = –0.1352 dbar   Mean = 0.0000 dbar
Maximum = 0.1214 dbar   Standard Deviation = 0.0428 dbar

40HRLP PRESSURE RECORDS

Figure 25

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 3, 1993	0600	–12378
LAST DATA POINT:	Jun 30, 1995	0600	4326

Number of Points: 2785
Sampling Interval: 6.0 hrs

Minimum = –0.1112 dbar
Maximum = 0.1073 dbar
Mean = 0.0000 dbar
Standard Deviation = 0.0412 dbar

TEMPERATURE RECORDS

Figure 20

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 1, 1993	185932	–12413.01
LAST DATA POINT:	Jul 2, 1995	215932	4389.99

Number of Points: 16763
Sampling Interval: 1.0 hrs

Minimum = 2.520°C
Maximum = 2.840°C
Mean = 2.653°C
Standard Deviation = 0.057°C

40HRLP TEMPERATURE RECORDS

Figure 26

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 3, 1993	0600	–12378
LAST DATA POINT:	Jun 30, 1995	0600	4326

Number of Points: 2785
Sampling Interval: 6.0 hrs

Minimum = 2.517 °C
Maximum = 2.838 °C
Mean = 2.652 °C
Standard Deviation = 0.056 °C

Table 3: **Site and Record Information for PIES95NAC40**

Serial Number: 65
Type of Travel Time Detector: TTC
Number of Pings per Sampling: 024
Additional Sensors: Pressure and Temperature
Pressure Sensor Serial Number: 36883

POSITION: 42°43.04N 47°23.21W DEPTH: 3897 m

	DATE	GMT	CRUISE
LAUNCH:	Aug 2, 1993	2042	OC259
RECOVERY:	Jun 30, 1995	1400	HU95011

TRAVEL TIME RECORDS
Figure 9

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 2, 1993	220232	–12385.96
LAST DATA POINT:	Jun 30, 1995	120232	4332.042

Number of Points: 16719
Sampling Interval: 1.0 hr

Minimum = 0.36626 s Mean = 0.38454 s
Maximum = 0.40225 s Standard Deviation = 0.00792 s
Unrecorded Constant = 4.8 s

40HRLP τ_{2000} RECORDS
Figure 24

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 3, 1993	1800	–12366
LAST DATA POINT:	Jun 29, 1995	1200	4308

Number of Points: 2780
Sampling Interval: 6.0 hrs

Minimum τ_{2000} = 2.6466 s Mean = 2.6623 s
Maximum τ_{2000} = 2.6773 s Standard Deviation = 0.0074 s

MEASURED PRESSURE RECORDS

Figure 13

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 2, 1993	223000	–12385.50
LAST DATA POINT:	Jun 30, 1995	113000	4331.50

Number of Points: 16718
Sampling Interval: 1.0 hrs

Minimum = 3955.09 dbar
Maximum = 3956.11 dbar
Mean = 3955.60 dbar
Standard Deviation = 0.17 dbar

RESIDUAL PRESSURE RECORDS

Figure 17

$$P_{residual} = P_{measured} - MEAN - TIDE$$

TIDE calculated from the following constituents:

	M2	N2	S2	K2	K1	O1	P1	Q1
H (dbar):	0.21280	0.04616	0.08080	0.02169	0.05221	0.03367	0.01726	0.00576
$G°$:	351.453	335.866	26.657	29.318	153.037	155.040	153.234	155.307

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 3, 1993	103000	–12373.50
LAST DATA POINT:	Jun 30, 1995	113000	4331.50

Number of Points: 16706
Sampling Interval: 1.0 hrs

Minimum = –0.2062 dbar
Maximum = 0.1332 dbar
Mean = 0.0000 dbar
Standard Deviation = 0.0445 dbar

40HRLP PRESSURE RECORDS

Figure 25

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 4, 1993	0600	–12354
LAST DATA POINT:	Jun 29, 1995	1200	4308

Number of Points: 2778
Sampling Interval: 6.0 hrs

Minimum = –0.1647 dbar Mean = 0.0000 dbar
Maximum = 0.1073 dbar Standard Deviation = 0.0430 dbar

TEMPERATURE RECORDS

Fig. 21

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 2, 1993	225932	–12385.01
LAST DATA POINT:	Jun 30, 1995	125932	4332.99

Number of Points: 16719
Sampling Interval: 1.0 hrs

Minimum = 2.221°C Mean = 2.320°C
Maximum = 2.366°C Standard Deviation = 0.023°C

40HRLP TEMPERATURE RECORDS

Fig. 26

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 4, 1993	1200	–12348
LAST DATA POINT:	Jun 29, 1995	1200	4308

Number of Points: 2777
Sampling Interval: 6.0 hrs

Minimum = 2.222 °C Mean = 2.303 °C
Maximum = 2.363 °C Standard Deviation = 0.023 °C

Table 4: **Site and Record Information for PIES95NAC65**

Serial Number: 75
Type of Travel Time Detector: TTC
Number of Pings per Sampling: 024
Additional Sensors: Pressure and Temperature
Pressure Sensor Serial Number: 36884

POSITION: 42°13.18N 45°39.84W DEPTH: 4698 m

	DATE	GMT	CRUISE
LAUNCH:	Aug 4, 1993	2116	OC259
RECOVERY:	Jun 29, 1995	2300	HU95011

TRAVEL TIME RECORDS
Figure 10

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 4, 1993	230225	–12336.96
LAST DATA POINT:	Mar 22, 1995	010225	1921.040

Number of Points: 14259
Sampling Interval: 1.0 hr

Minimum = 0.25039 s Mean = 0.26647 s
Maximum = 0.28444 s Standard Deviation = 0.00531 s
Unrecorded Constant = 6.0 s

40HRLP τ_{2000} RECORDS
Figure 24

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 6, 1993	0000	–12312
LAST DATA POINT:	Mar 21, 1995	0000	1896

Number of Points: 2369
Sampling Interval: 6.0 hrs

Minimum = 2.6270 s Mean = 2.6411 s
Maximum = 2.6556 s Standard Deviation = 0.0049 s

MEASURED PRESSURE RECORDS

Figure 14

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 4, 1993	233000	–12336.50
LAST DATA POINT:	Jun 29, 1995	173000	4313.50

Number of Points: 16651
Sampling Interval: 1.0 hrs

Minimum = 4824.18 dbar   Mean = 4824.83 dbar
Maximum = 4825.36 dbar   Standard Deviation = 0.19 dbar

RESIDUAL PRESSURE RECORDS

Figure 18

$$P_{residual} = P_{measured} - MEAN - TIDE$$

TIDE calculated from the following constituents:

	M2	N2	S2	K2	K1	O1	P1	Q1
H (dbar):	0.20460	0.04430	0.08062	0.02167	0.04771	0.02807	0.01575	0.00443
G°:	0.602	344.567	32.044	34.064	149.377	153.645	149.039	165.504

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 5, 1993	113000	–12324.50
LAST DATA POINT:	Jun 29, 1995	173000	4313.50

Number of Points: 16639
Sampling Interval: 1.0 hrs

Minimum = –0.3449 dbar   Mean = 0.0000 dbar
Maximum = 0.2680 dbar   Standard Deviation = 0.0822 dbar

40HRLP PRESSURE RECORDS

Figure 25

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 6, 1993	1200	–12300
LAST DATA POINT:	Jun 28	1800	4290

Number of Points: 2766
Sampling Interval: 6.0 hrs

Minimum = –0.3249 dbar   Mean = 0.0000 dbar
Maximum = 0.2460 dbar   Standard Deviation = 0.0809 dbar

TEMPERATURE RECORDS

Figure 22

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 3, 1993	175932	–12336.01
LAST DATA POINT:	Mar 12, 1994	235932	–7056.01

Number of Points: 5281
Sampling Interval: 1.0 hrs

Minimum = 2.395°C   Mean = 2.442°C
Maximum = 2.507°C   Standard Deviation = 0.015°C

40HRLP TEMPERATURE RECORDS

Figure 26

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 6, 1993	1200	–12300
LAST DATA POINT:	Mar 12, 1994	1800	–7062

Number of Points: 874
Sampling Interval: 6.0 hrs

Minimum = 2.396 °C   Mean = 2.442 °C
Maximum = 2.486 °C   Standard Deviation = 0.014 °C

Table 5: **Site and Record Information for PIES95NAC80**

Serial Number: 71
Type of Travel Time Detector: TTC
Number of Pings per Sampling: 024
Additional Sensors: Pressure and Temperature
Pressure Sensor Serial Number: 31724

POSITION: 41°54.36N 44°34.46W DEPTH: 4840 m

	DATE	GMT	CRUISE
LAUNCH:	Aug 5, 1993	1652	OC259
RECOVERY:	Jun 29, 1995	1417	HU95011

TRAVEL TIME RECORDS
Figure 11

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 5, 1993	180239	–12317.96
LAST DATA POINT:	Jun 29, 1995	120239	4308.044

Number of Points: 16627
Sampling Interval: 1.0 hr

Minimum = 0.05065 s Mean = 0.06248 s
Maximum = 0.09826 s Standard Deviation = 0.00619 s
Unrecorded Constant = 6.4 s

40HRLP τ_{2000} RECORDS
Figure 24

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 6, 1993	1800	–12294
LAST DATA POINT:	Jun 28, 1995	1200	4284

Number of Points: 2764
Sampling Interval: 6.0 hrs

Minimum τ_{2000} = 2.6197 s Mean = 2.6302 s
Maximum τ_{2000} = 2.6628 s Standard Deviation = 0.0058 s

MEASURED PRESSURE RECORDS

Figure 15

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 5, 1993	183000	–12317.5
LAST DATA POINT:	Jun 29, 1995	113000	4307.5

Number of Points: 16626
Sampling Interval: 1.0 hrs

Minimum = 4988.18 dbar
Maximum = 4989.51 dbar
Mean = 4988.99 dbar
Standard Deviation = 0.20 dbar

RESIDUAL PRESSURE RECORDS

Figure 19

$$P_{residual} = P_{measured} - MEAN - TIDE$$

TIDE calculated from the following constituents:

	M2	N2	S2	K2	K1	O1	P1	Q1
H (dbar):	0.20707	0.04491	0.08307	0.02236	0.04519	0.02378	0.01472	0.00403
$G°$:	6.319	350.588	35.152	36.804	145.496	152.057	145.027	168.884

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 6, 1993	063000	–12305.5
LAST DATA POINT:	Jun 29, 1995	113000	4307.5

Number of Points: 16614
Sampling Interval: 1.0 hrs

Minimum = –0.4714 dbar
Maximum = 0.2605 dbar
Mean = 0.0000 dbar
Standard Deviation = 0.1097 dbar

40HRLP PRESSURE RECORDS

Figure 25

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 7, 1993	0600	–12282
LAST DATA POINT:	Jun 28, 1995	1200	4284

Number of Points: 2762
Sampling Interval: 6.0 hrs

Minimum = –0.4531 dbar
Maximum = 0.2424 dbar
Mean = 0.0000 dbar
Standard Deviation = 0.1091 dbar

TEMPERATURE RECORDS

Figure 23

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 5, 1993	185932	–12317.01
LAST DATA POINT:	Jun 29, 1995	125932	4308.99

Number of Points: 16627
Sampling Interval: 1.0 hrs

Minimum = 2.336°C
Maximum = 2.451°C
Mean = 2.386°C
Standard Deviation = 0.0191°C

40HRLP TEMPERATURE RECORDS

Figure 26

	DATE	GMT	YEARHOUR
1st DATA POINT:	Aug 7, 1993	0600	–12282
LAST DATA POINT:	Jun 28, 1995	1800	4290

Number of Points: 2763
Sampling Interval: 6.0 hrs

Minimum = 2.338 °C
Maximum = 2.447 °C
Mean = 2.386 °C
Standard Deviation = 0.019 °C

5 Plots of Hourly Data Records for Each Instrument

Plots are presented for the individual time series of travel time, pressure, residual pressure (tides and mean removed), and temperature. The plots are grouped by sensor, with the travel time records for all four instruments shown first.

A common time axis, that starts at August 1, 1993 (yearhour -12432) and extends to August 1, 1995 (yearhour 5088), is used. This time period is displayed in four panels on each page, with a six-month time period plotted in each panel. Small tic marks indicate 0000 UT of each day and weekly intervals (168 hours) are denoted by large ticks.

The vertical axes for each sensor are consistent between instruments. Travel times are plotted within a 50-ms vertical window with increments of 5 ms. Pressures are plotted in a 2 dbar window, with the mean pressure indicated on the vertical axis removed. Residual pressures are plotted in 0.75 dbar window, with each tic denoting 0.05 dbar. Temperatures are plotted within a 0.4°C window.

The sampling interval of all records is hourly. The start time, end time, and length of the records are tabulated in Section 4.

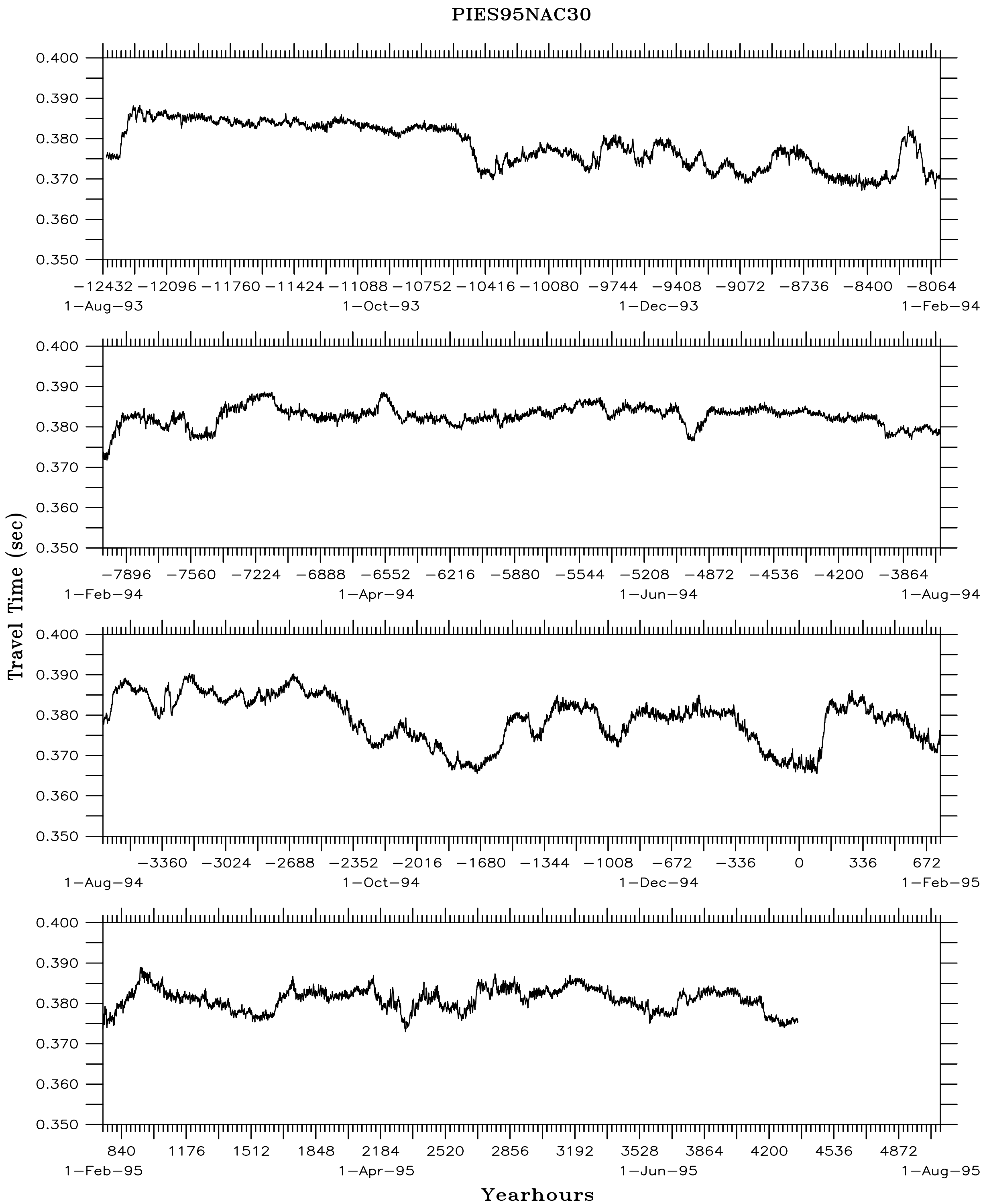

Figure 8: PIES95NAC30 Travel Time Record

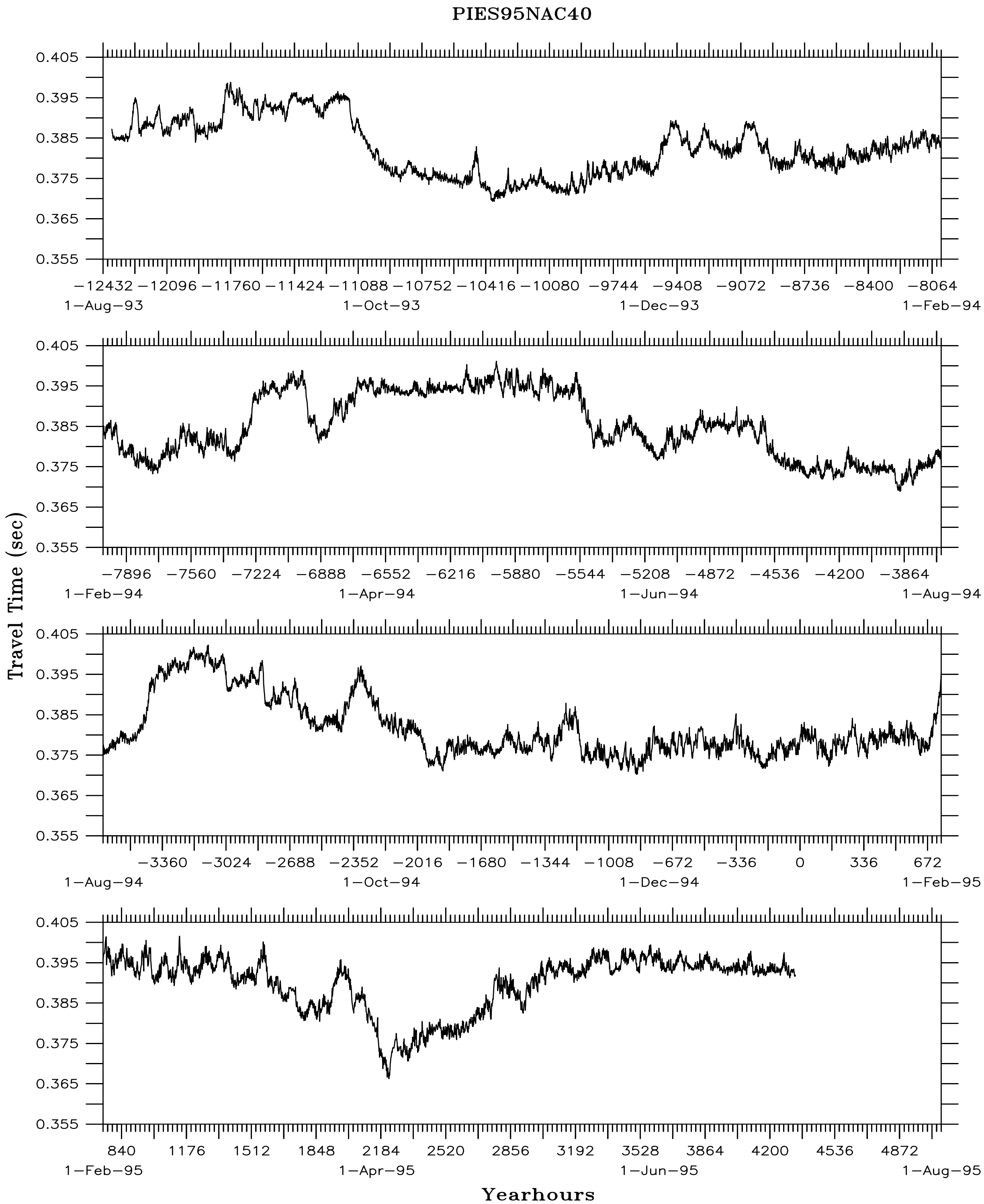

Figure 9: PIES95NAC40 Travel Time Record

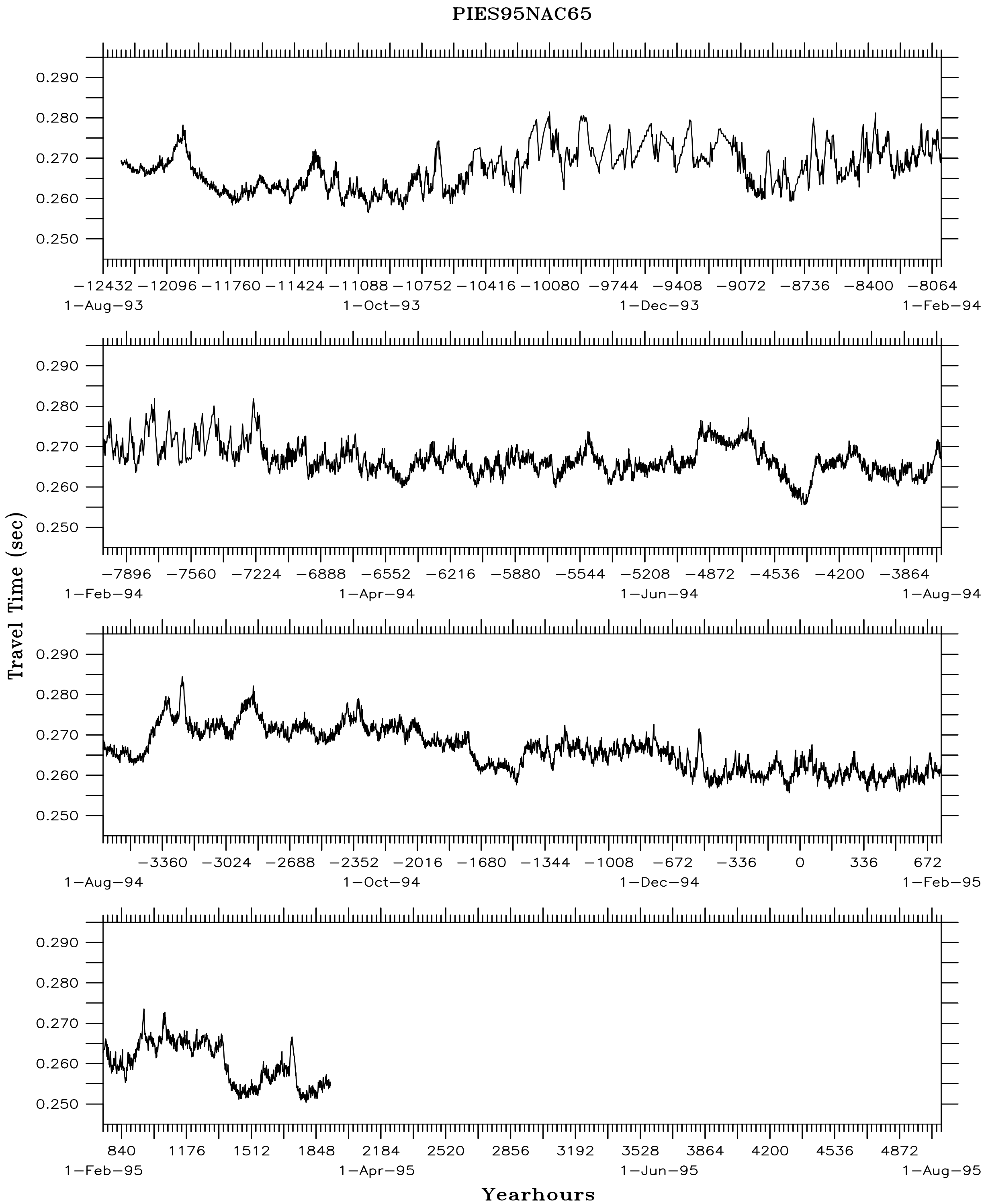

Figure 10: PIES95NAC65 Travel Time Record

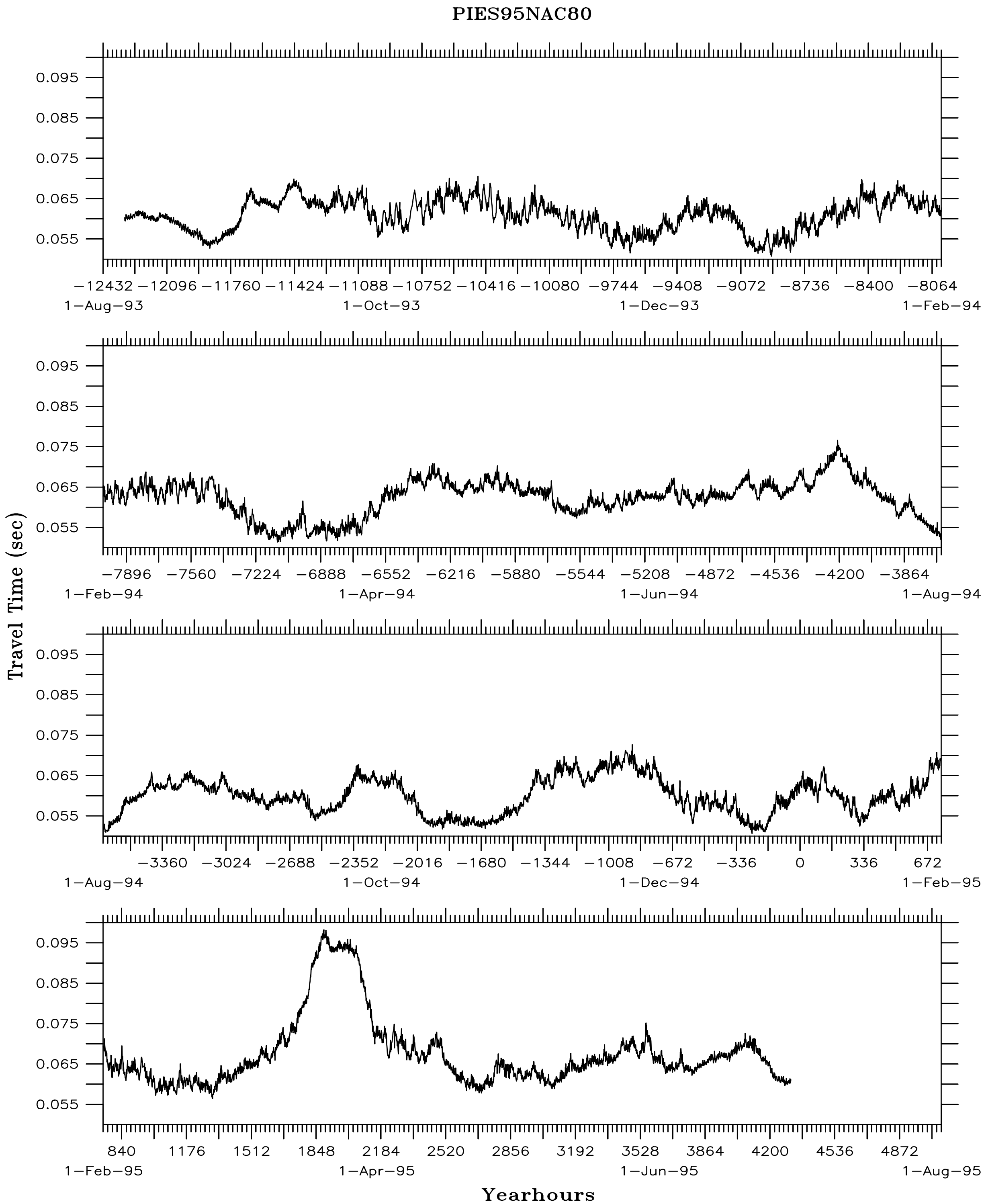

Figure 11: PIES95NAC80 Travel Time Record

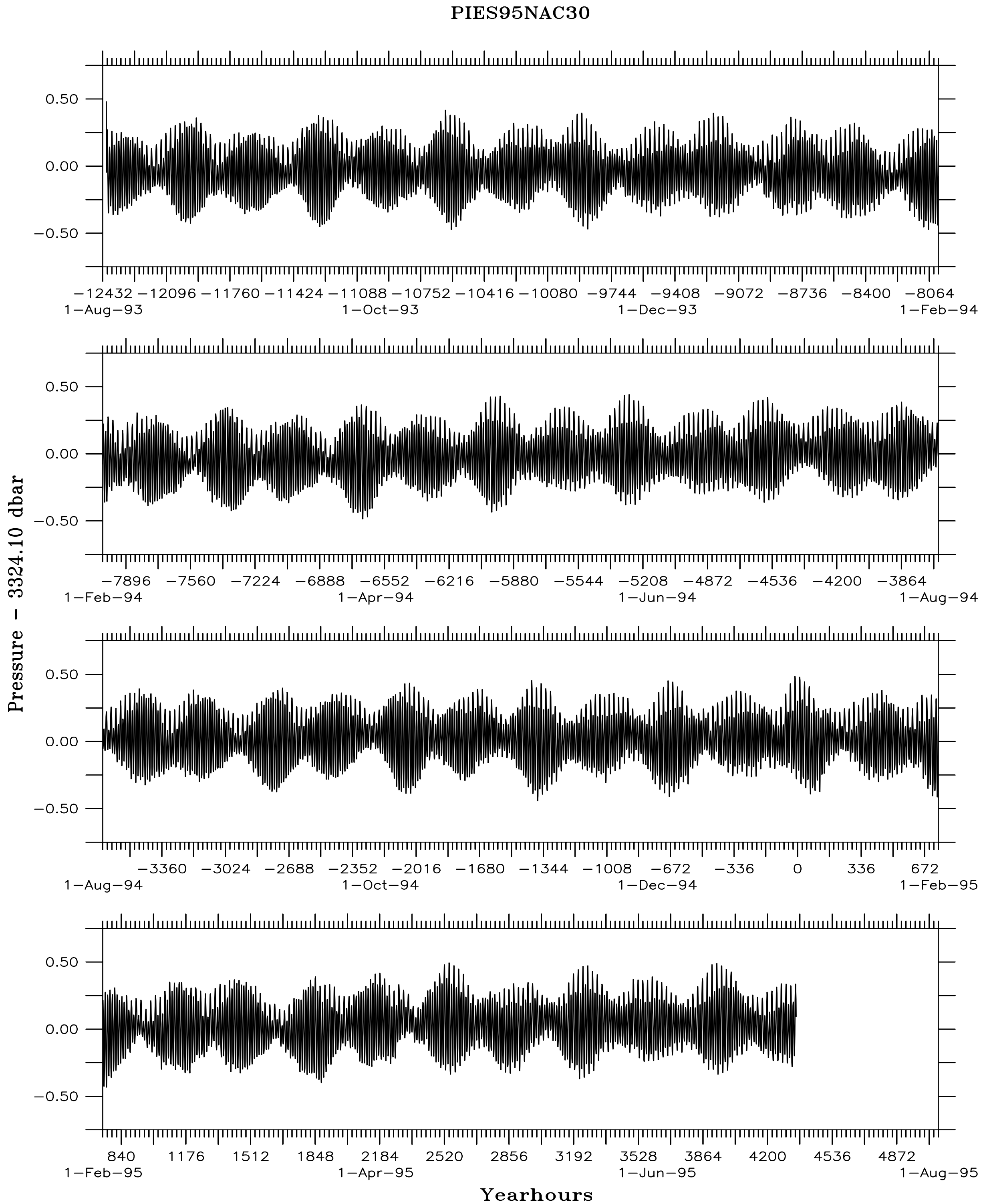

Figure 12: PIES95NAC30 Pressure Record

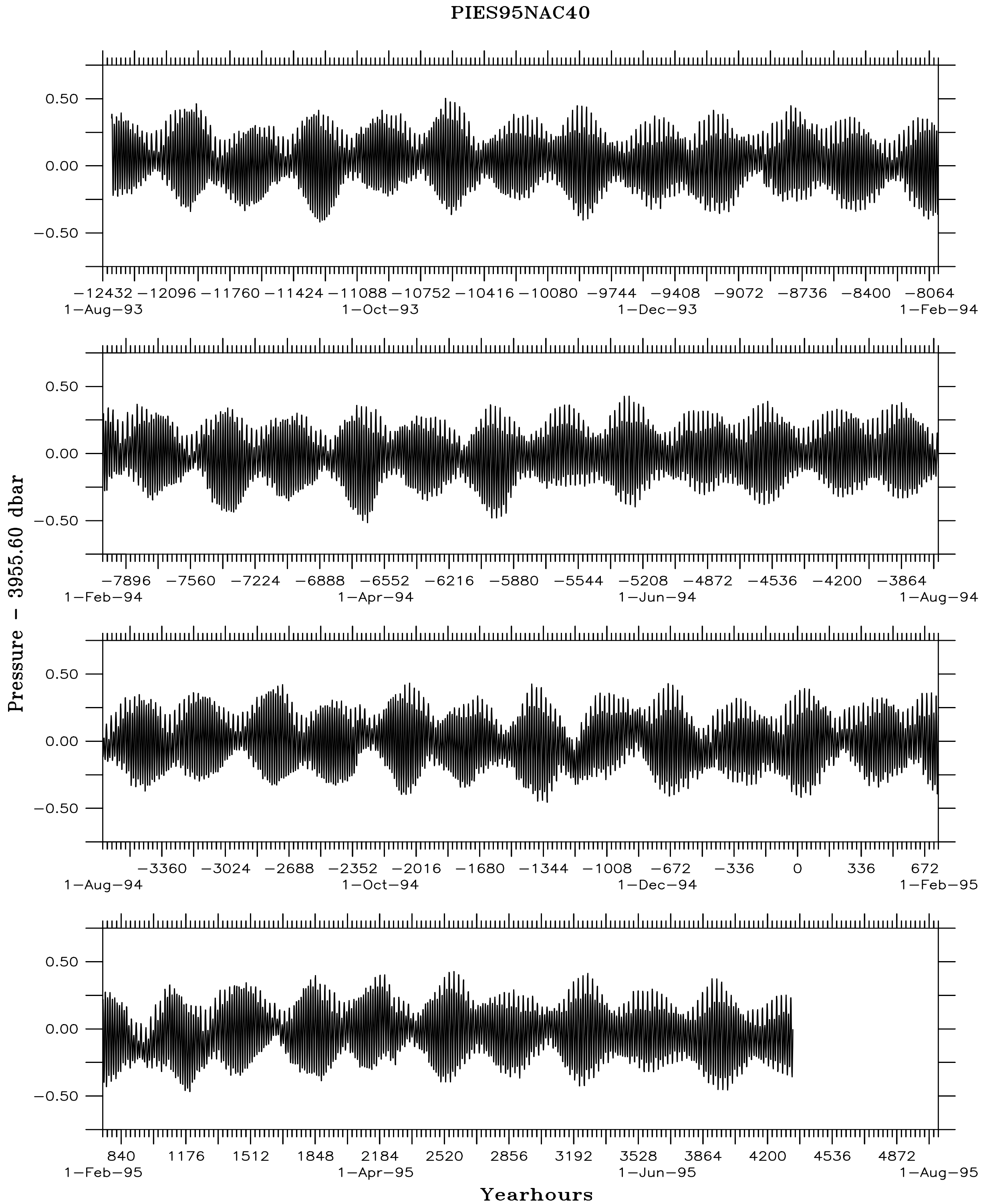

Figure 13: PIES95NAC40 Pressure Record

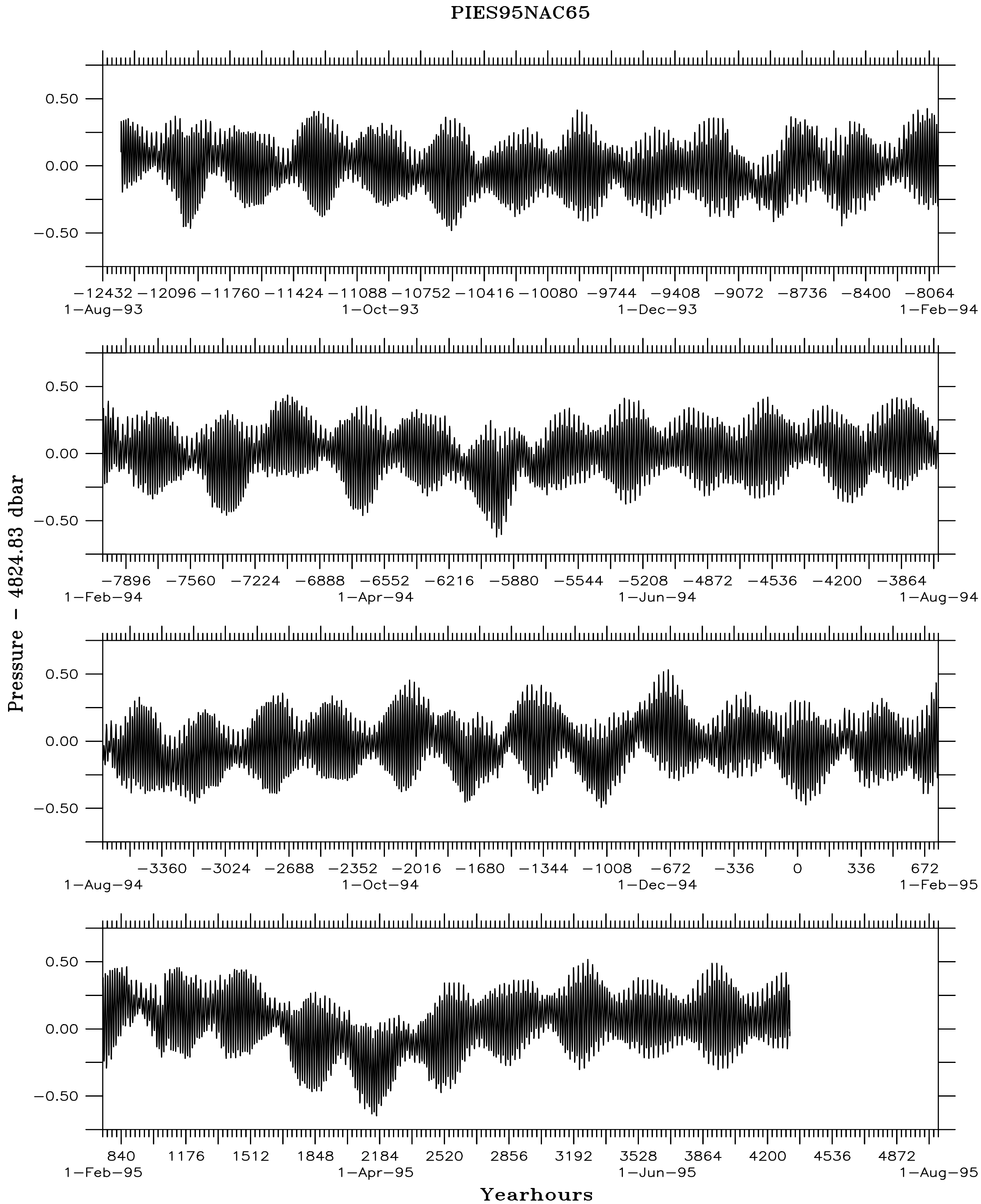

Figure 14: PIES95NAC65 Pressure Record

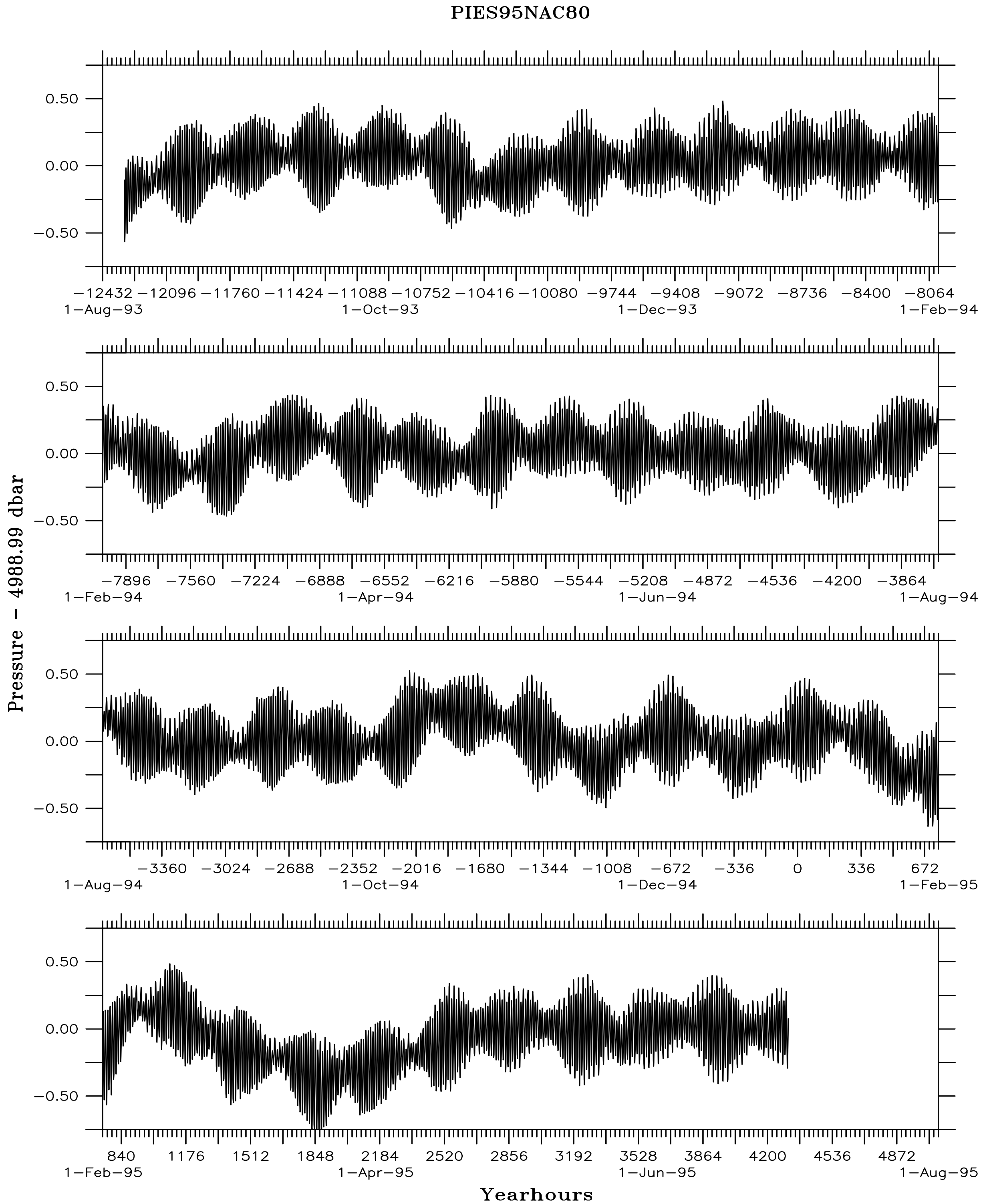

Figure 15: PIES95NAC80 Pressure Record

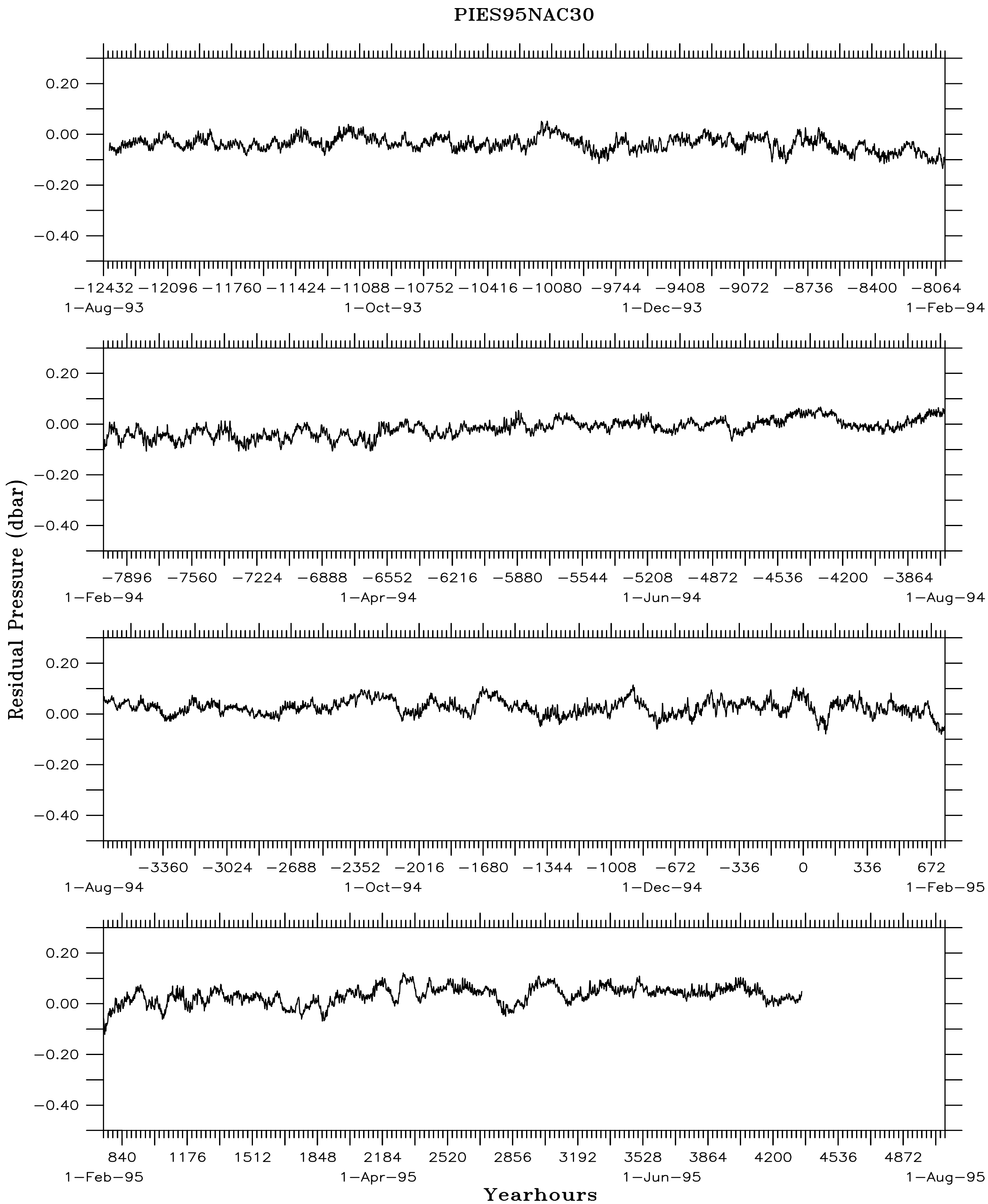

Figure 16: PIES95NAC30 Residual Pressure Record

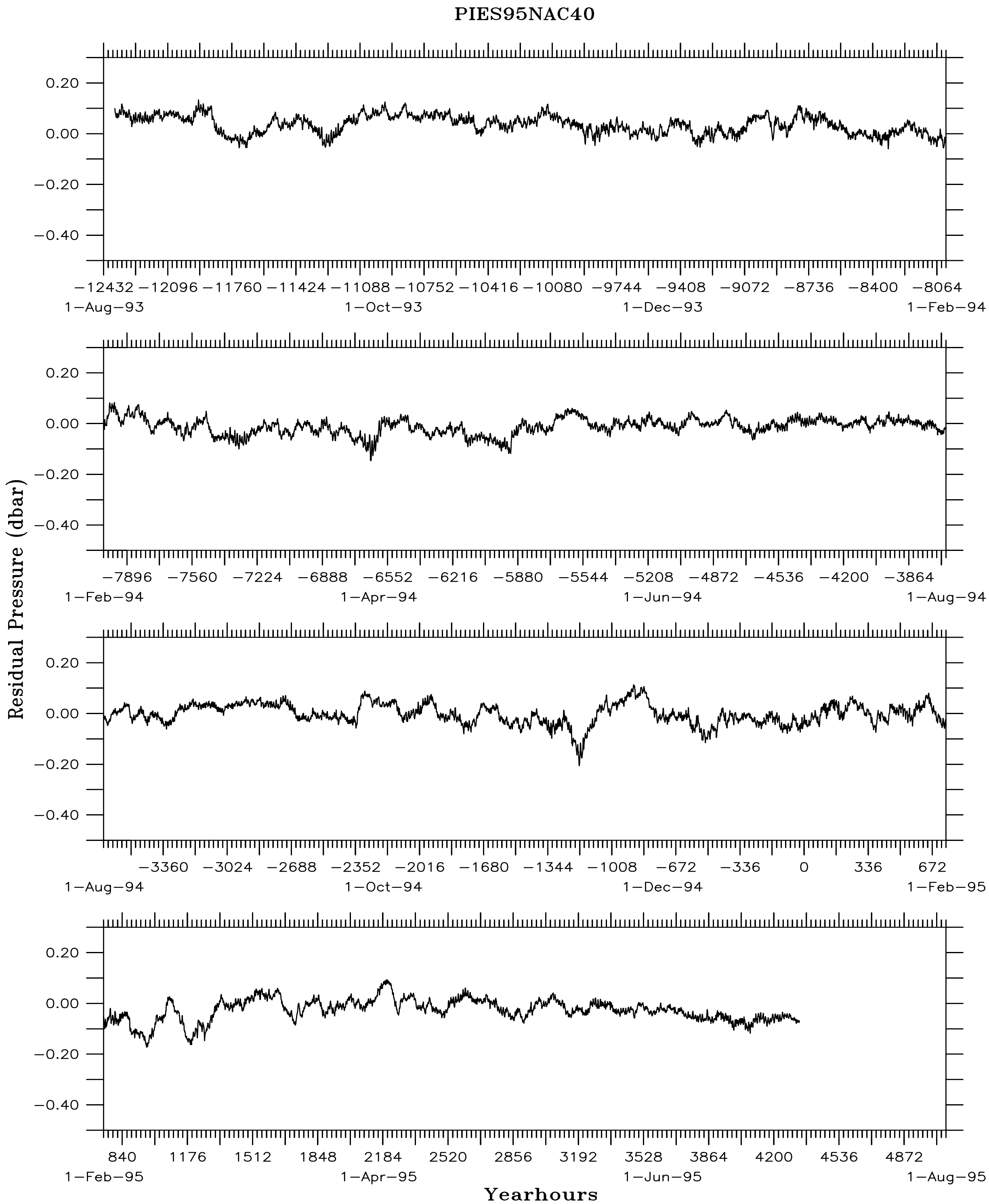

Figure 17: PIES95NAC40 Residual Pressure Record

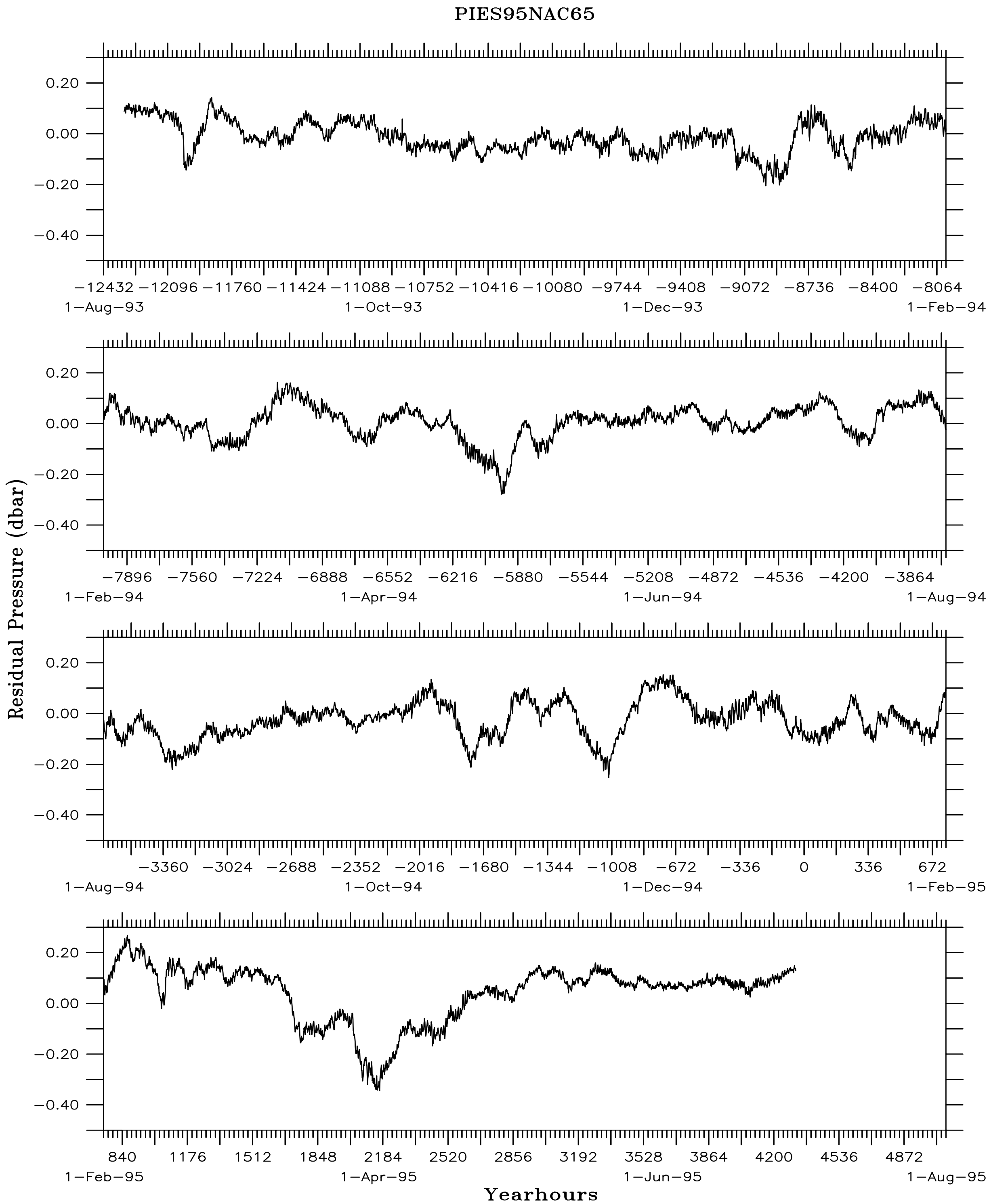

Figure 18: PIES95NAC65 Residual Pressure Record

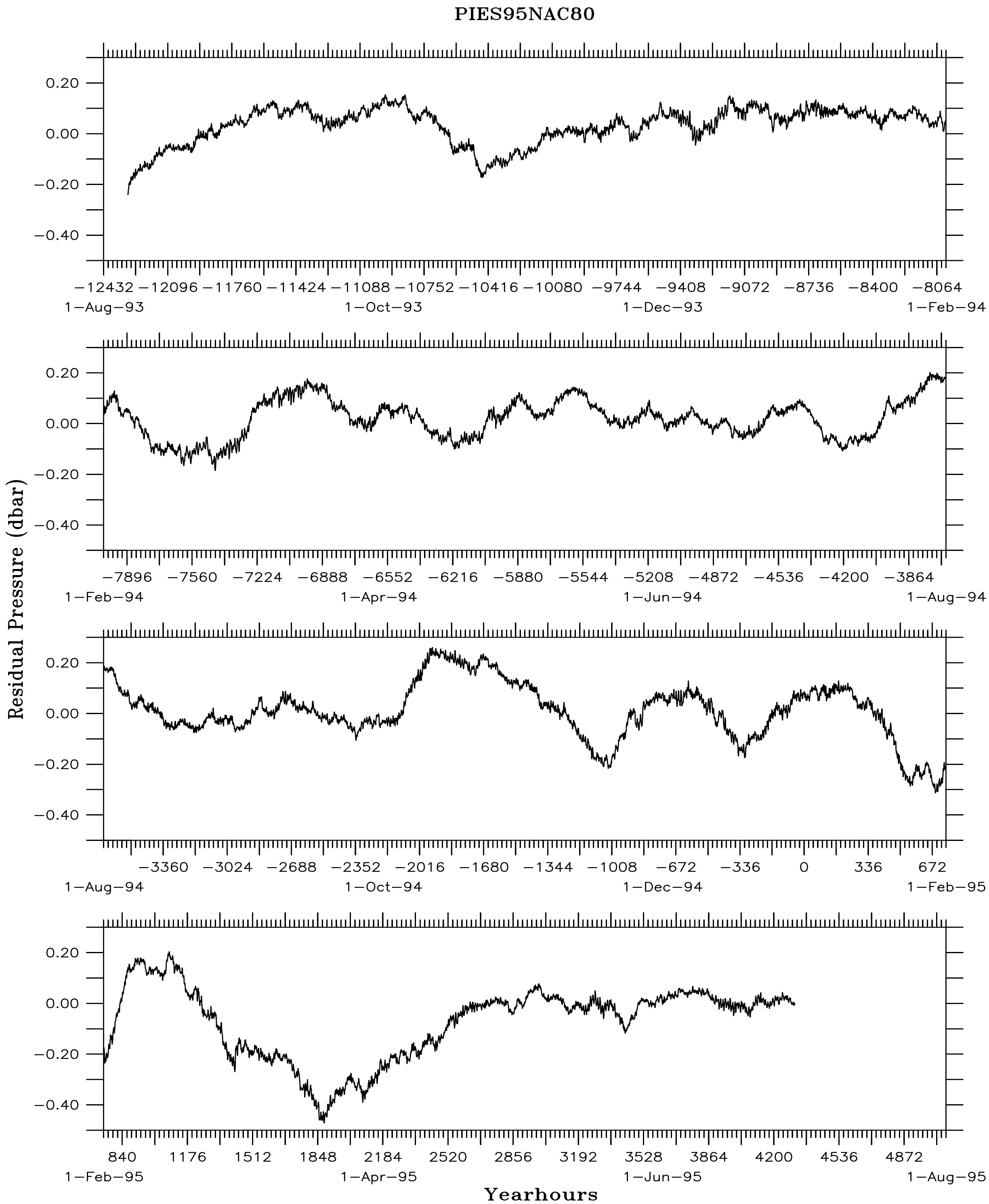

Figure 19: PIES95NAC80 Residual Pressure Record

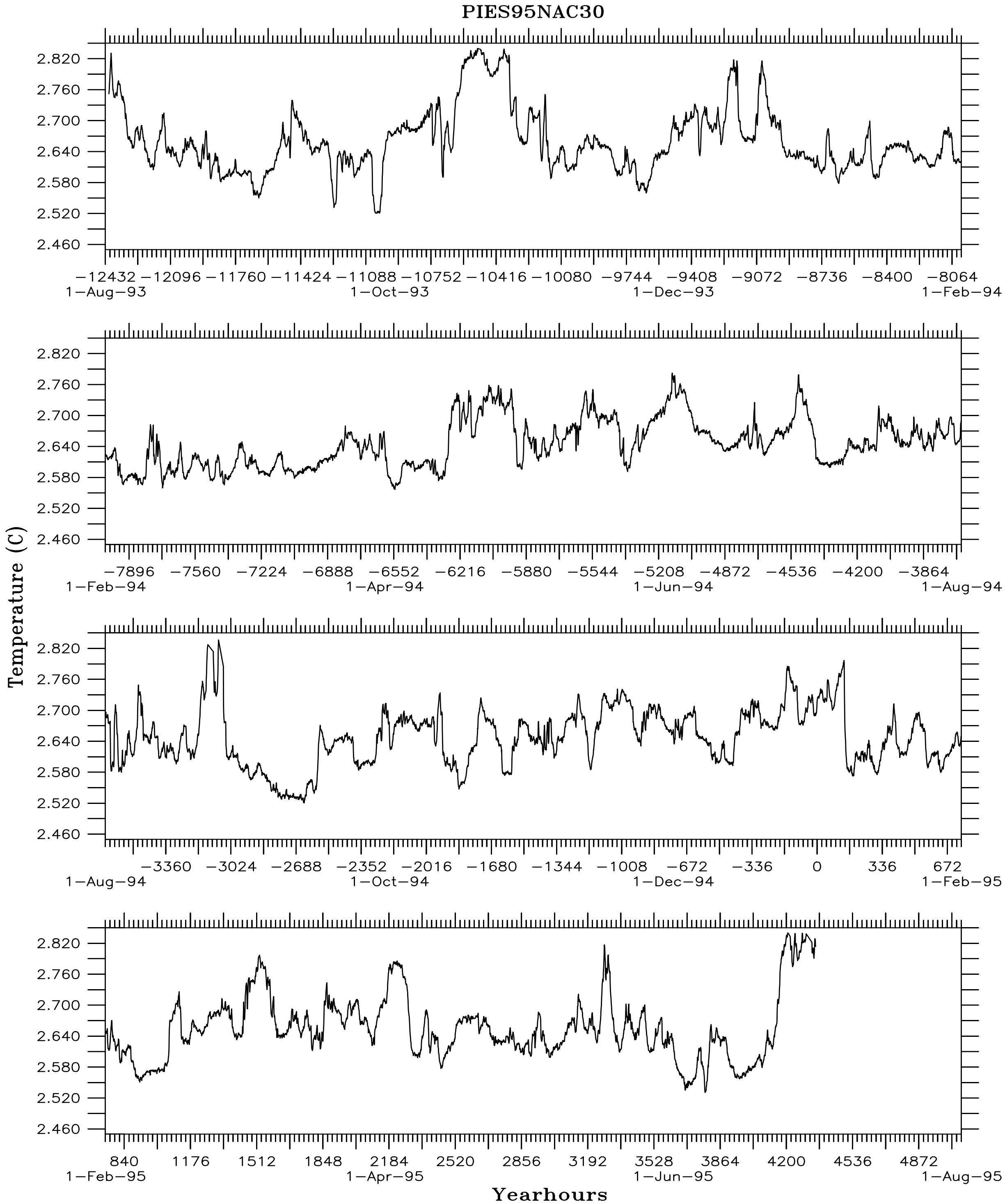

Figure 20: PIES95NAC30 Temperature Record

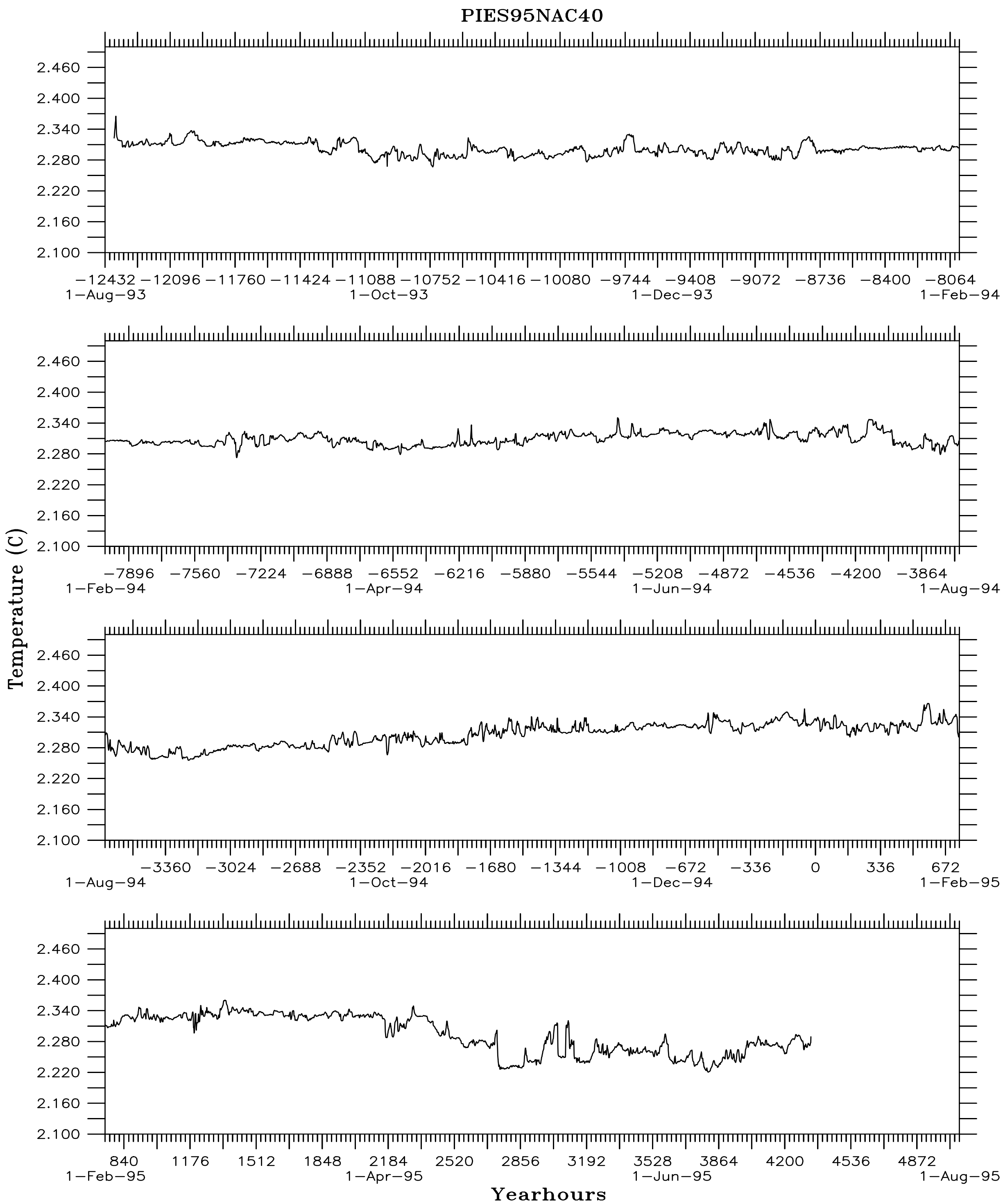

Figure 21: PIES95NAC40 Temperature Record

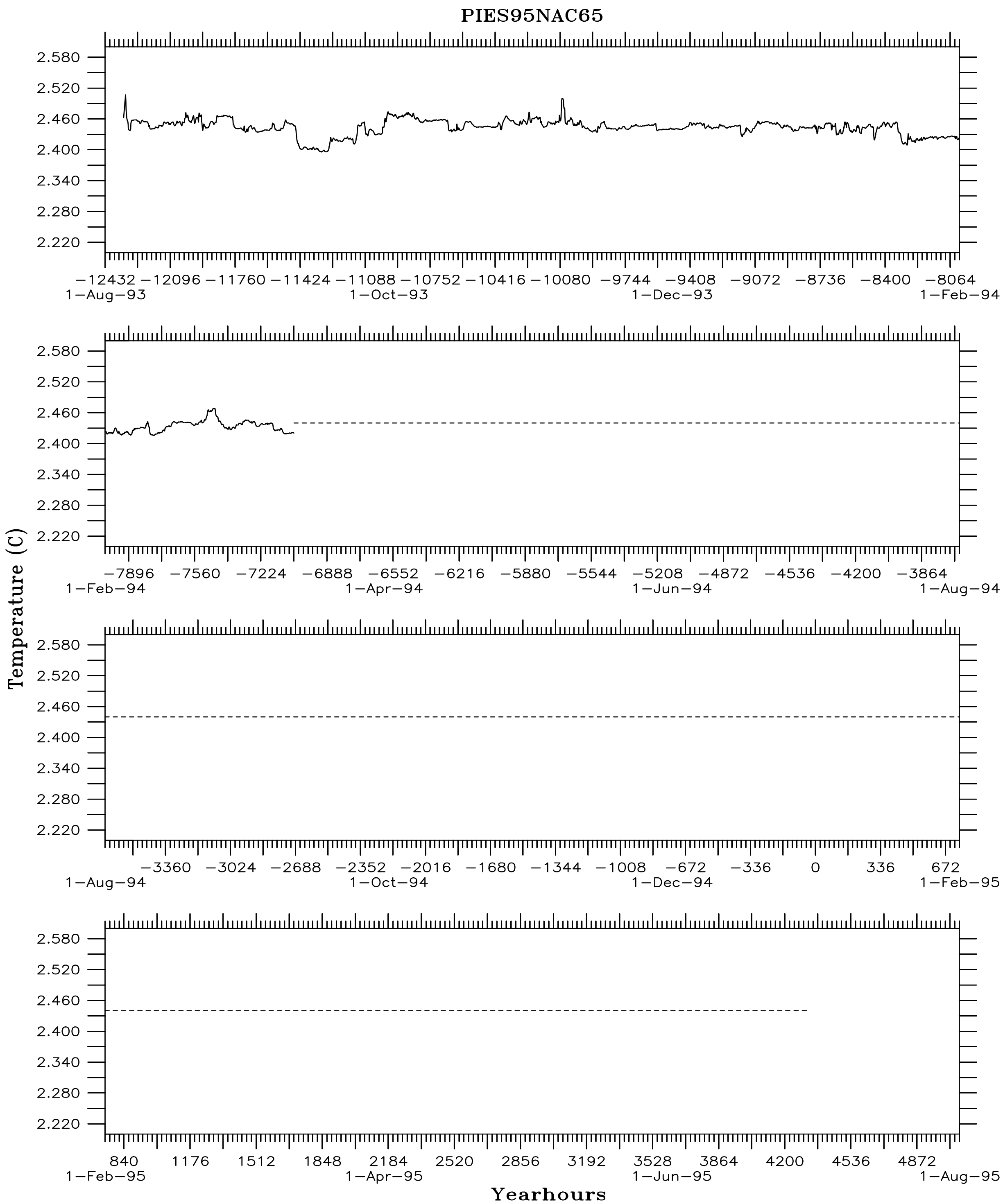

Figure 22: PIES95NAC65 Temperature Record

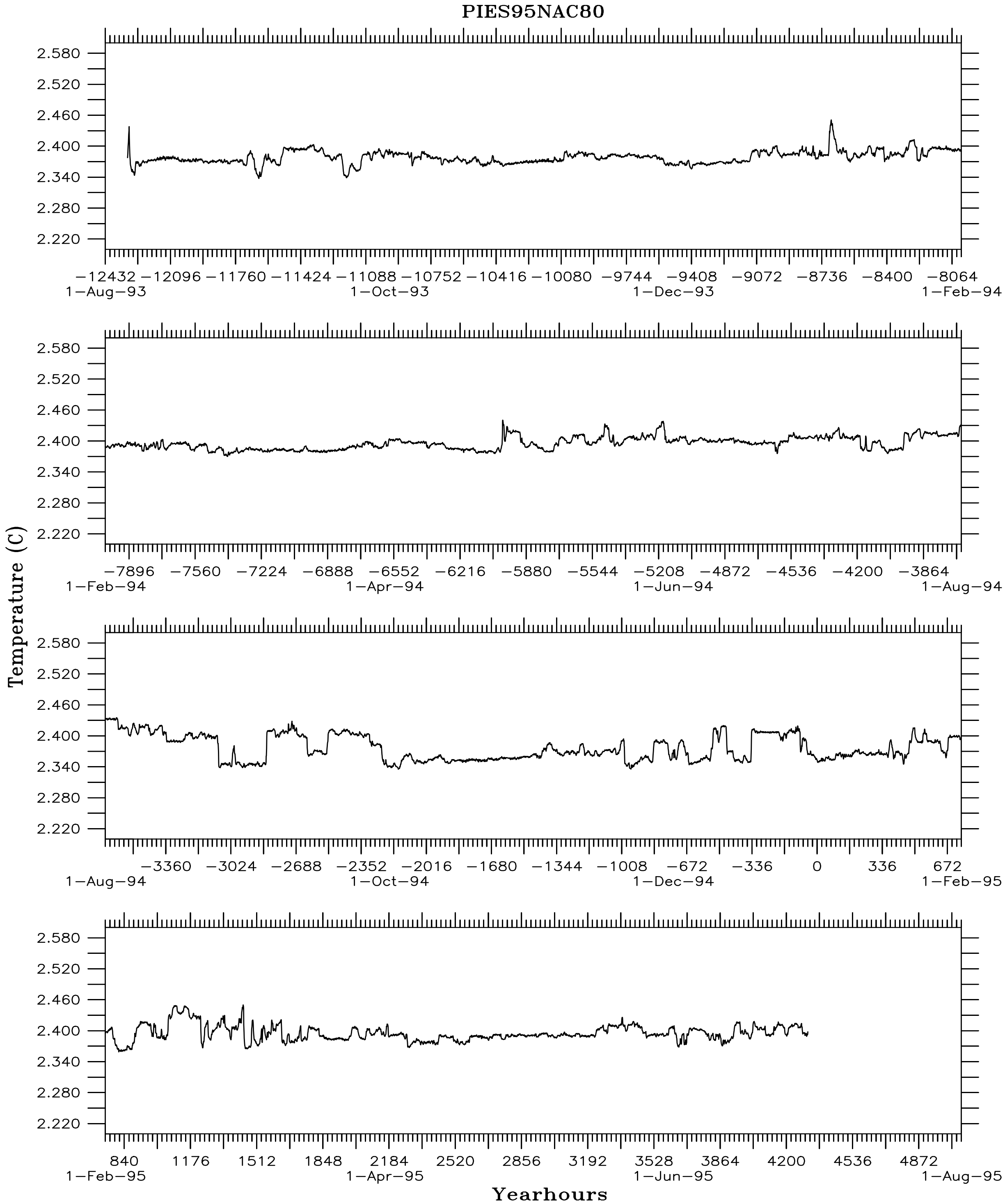

Figure 23: PIES95NAC80 Temperature Record

6 Plots of 40 HRLP Data Records for Each Instrument

The 40-hr low-pass filtered τ_{2000}, pressure and temperature records are plotted. The data are grouped by sensor, such that the data records for all four instruments are shown in separate panels on the same page.

The time axes span the same two-year period described in the previous section. The yearhours are not displayed; only the corresponding months and years are labelled.

The sampling interval is 6 hours for all variables, with samples given at 0000, 0600, 1200, and 1800 UT on each day. Record lengths, start times, and end times of all plots are tabulated in Section 4.

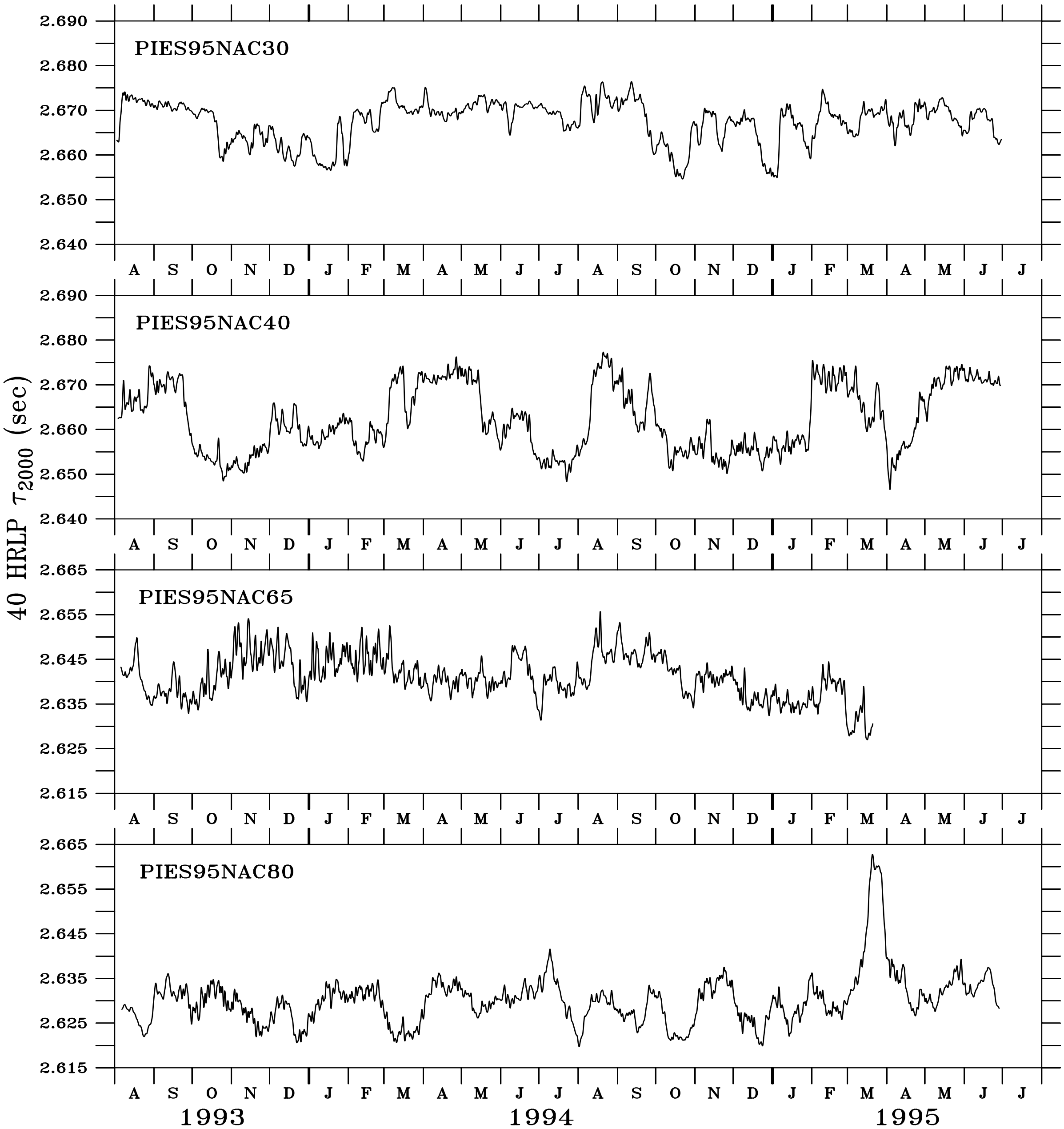

Figure 24: 40 HRLP τ_{2000} Records

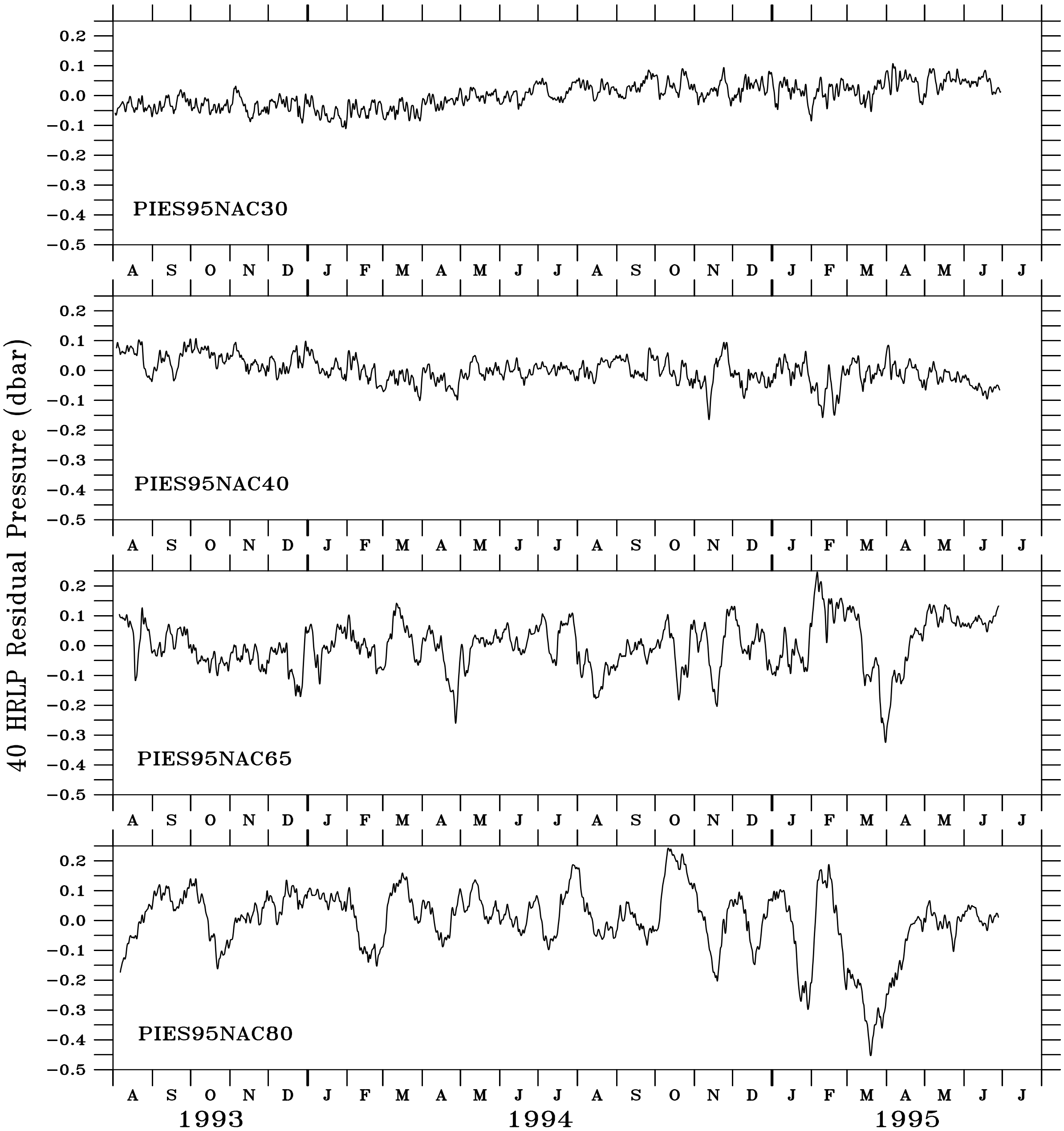

Figure 25: 40 HRLP Residual Pressure Records

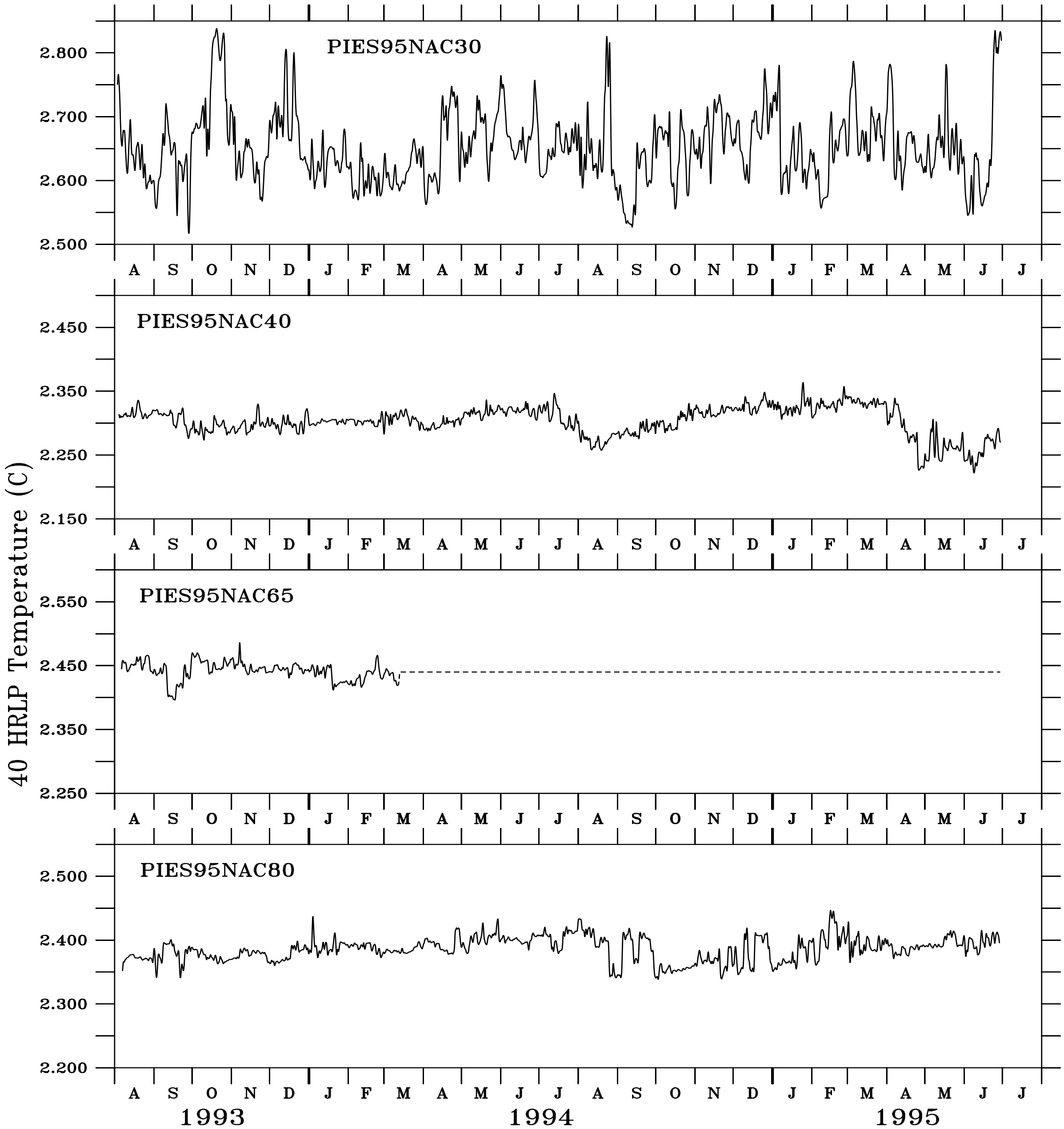

Figure 26: 40 HRLP Temperature Records

Acknowledgments

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